Northern Territory Government

DEPARTMENT OF LAND RESOURCE MANAGEMENT

Technical Report

Great Artesian Basin Resource Assessment

Report 14/2012A

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Cover Image:- McDills No. 1

Water Resources Branch drilling crew during the rehabilitation of McDills No. 1 Bore, 2001.

Courtesy of Peter Jolly

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1. Introduction

1.1. Background to the Report

The Great Artesian Basin (GAB) is an extensive groundwater system which underlies over a fifth of the Australian continent. Around 5% of this resource is located in the Northern Territory (NT). On the 29th January 2010, the Northern Territory Minister for Natural Resources, Environment and Heritage declared this area a Water Control District (WCD). This declaration marks the formal commencement of the Water Allocation Plan (WAP) process. On completion, the WAP will form the instrument through which the NT Government will manage all surface and groundwater resources within the GAB WCD.

This report has been prepared by the Department of Land Resource Management (DLRM), formerly known as NRETAS, to provide a scientific platform for the GAB WAP process. The WAP aims to apply a policy basis to allocate water for non-consumptive uses including environmental and cultural values, allocations for consumptive use are made from the remaining available water resource.

1.2. Scope and Objectives

The report is a technical document that aims to describe the current state of the GAB groundwater resource in the NT to the extent of current knowledge. The report has the following objectives:

- Collate existing data on the GAB resource within the NT.
- Provide an assessment of the groundwater resource on the basis of existing data.
- Identify any activities or processes which may threaten the long term sustainability of the water resource.
- Identify data gaps which limit the accuracy of the current assessment, particularly information that may affect management of the resource under the WAP process.

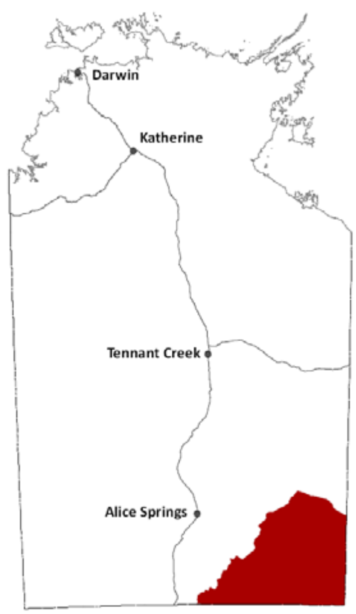


Figure 1-1 Great Artesian Basin Water Control District

2. Characteristics of the Water Control District

2.1. Overview of the Great Artesian Basin

The Great Artesian Basin (GAB) is Australia's largest water resource and is one of the largest artesian groundwater basins in the world (Habermehl, 1980). It extends over 1.7 million km^2 or 22% of the Australian continent (Cox and Barron, 1998) and underlies a significant proportion of Queensland and large areas of New South Wales, South Australia (SA) and the Northern Territory.

Discovery of the groundwater resource in the 1880's enabled the population of previously uninhabitable country and was the catalyst for the development of the pastoral industry in arid inland Australia. More recently the GAB provides an increasingly important source of water for the mining industry. There are thousands of springs tapping the GAB, arguably the most significant are the iconic mound springs located on the south-west margin of the basin in South Australia. These natural discharge features have immense cultural and environmental value. Their cultural significance to Aboriginal Australians indigenous to the area is well documented and extends for thousands of years prior to European settlement. From an environmental perspective, the mound springs represent a unique ecosystem in the arid zone and sustain important populations of endemic plants, fish and invertebrates.

In the Northern Territory the GAB occupies 84,500 km^2 - around 6% of the total area of the NT. Primarily, the GAB occurs in the south-east corner of the NT, however, there is also a small segment of the basin margin mapped further north in the gulf country (see **Figure 2-1**). The WCD and the scope of this assessment report do not address this northern outlier of the GAB[1]. Relative to the other states the NT contains only a small proportion of the GAB – less than 5% of the total basin area.

The first recorded bore drilled into the NT GAB was in 1894 at Charlotte Waters on the NT/SA border. The bore was drilled by the South Australian Government as a water supply for the Charlotte Waters telegraph station. This was followed shortly after in 1898 by the completion of the first artesian bore, Anacoora. Over the last 110 years around another 80 bores have been drilled and constructed in the GAB aquifer in the NT - the vast majority of these are located along the basin margin and are predominantly used to provide stock and domestic water supply.

[1] DLRM water resources drilled an investigation bore (RN035868) in this northern section in 2007. The Rolling Downs Group was encountered in this hole, however, no water bearing GAB sequences were intersected. It was concluded that within the NT the GAB aquifer isn't present on the northern periphery of the basin.

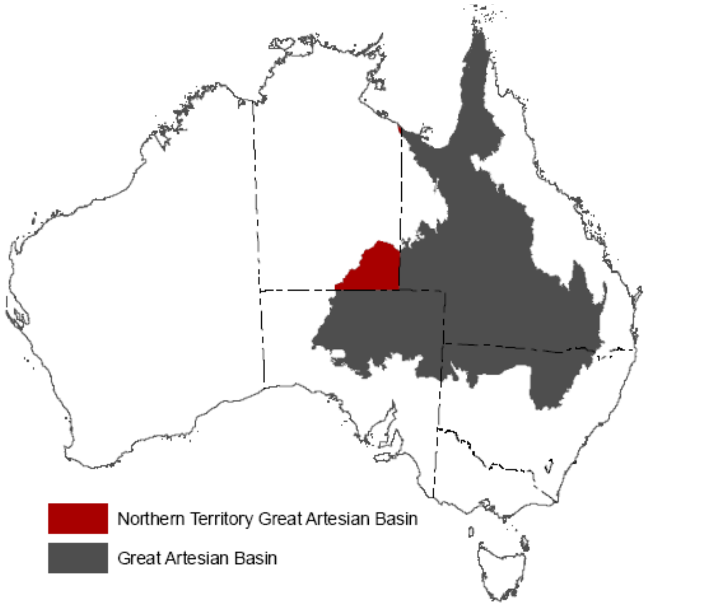


Figure 2-1 Regional map of the Great Artesian Basin

2.2. Physiography and Biogeographic Regions

The topography across the WCD is low lying with the highest elevations occurring on the western and northern edges (see **Figure 2-2**). This area is coincident with the margin of the GAB, flat topped outcrop of Jurassic and Cretaceous rocks form distinctive mesas which reach up to around 400mAHD. The regional ground surface slopes gently toward the south east corner of the WCD where elevations drop to around 50mAHD. The landscape of the WCD is dominated by the Simpson Desert, which is characterised by long linear dunes with a NNW orientation. These dunes can extend for several hundred kilometres and reach heights of up to 40m (Ambrose *et al*, 2006). Several large ephemeral rivers drain into and terminate in the WCD. The northern rivers (Hay and Plenty) run parallel to the Simpson Desert Dunefields. In contrast the Finke River in the south of the WCD takes a meandering form. It is an ancient river system and has played a significant role in the evolution of the landscape around the current day channel. The interior of the Simpson Desert contains large playas including Lake Caroline and the Plenty Lakes.

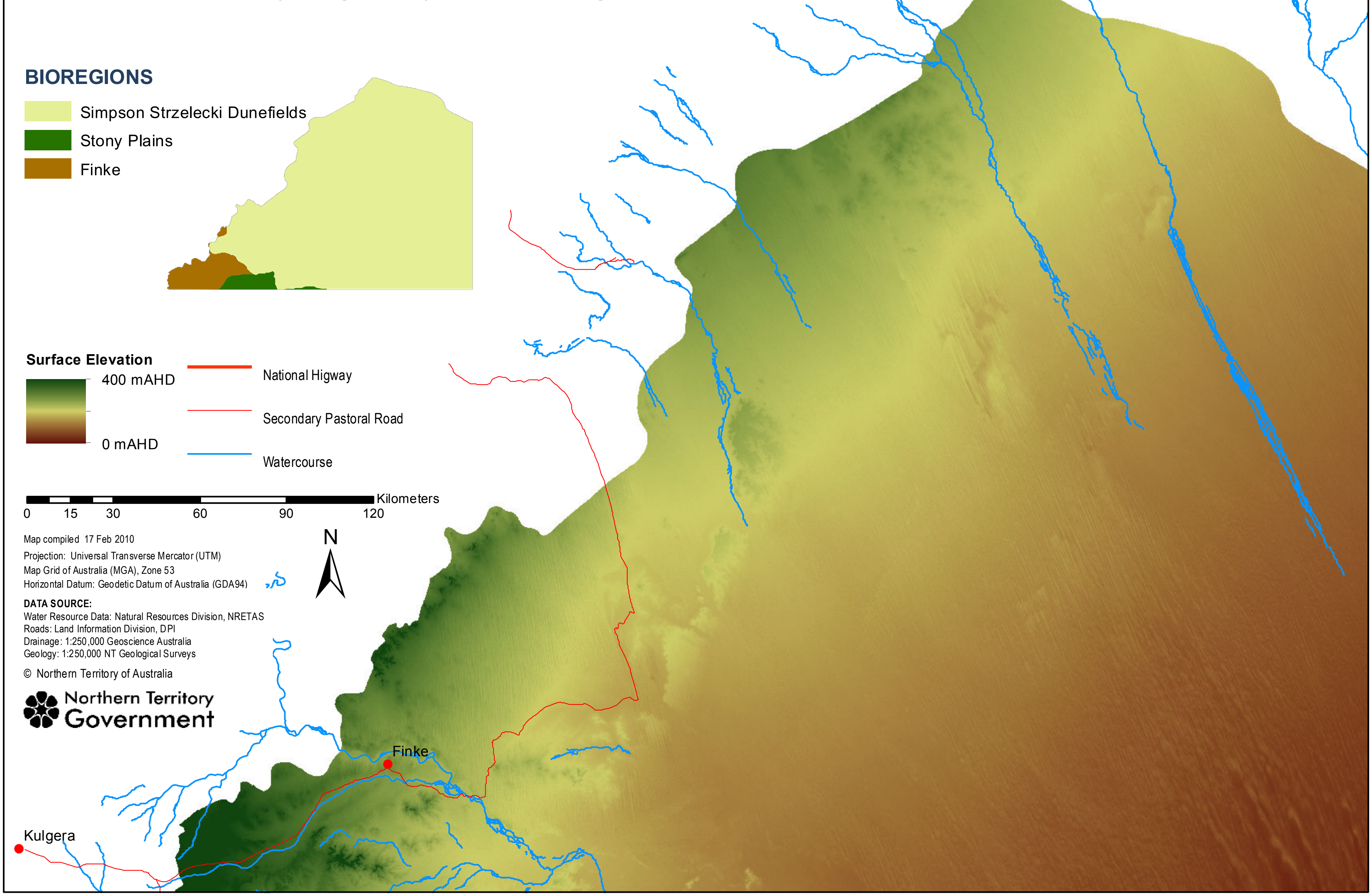
The WCD contains three bioregions under the IBRA classification system developed by Thackway and Creswell (1995). In order of relative area covered in the WCD these are:

- The Simpson Strzelecki Dunefields, which is the dominant bioregion in the WCD covering over 90% of the total WCD area (see **Figure 2-2**). The landform is dominated by sands dunes, sand fields and contains extensive areas of saline playas (Cox and Barron, 1998). It is vegetated with sparse shrubland and Spinifex grassland.

- The Stony Plains bioregion occurs over a small strip of land on the NT/SA border. This region is characterised by rocky country dominated by gibber and gypsum plains. It is sparsely vegetated by low chenepod (*Atriplex* and *Maireana spp.*) shrublands.

- The Finke bioregion encompasses the floodplain of the Finke River in the southwest of the WCD. It is characterised by sand plains with dissected uplands and valleys, including floodplains of three major rivers (Finke, Hugh and Palmer). Mulga is the dominant vegetation with various *Senna, Eremophilla* and *Acacia* species present.

FIGURE 2-2 - Physiography and Bioregions



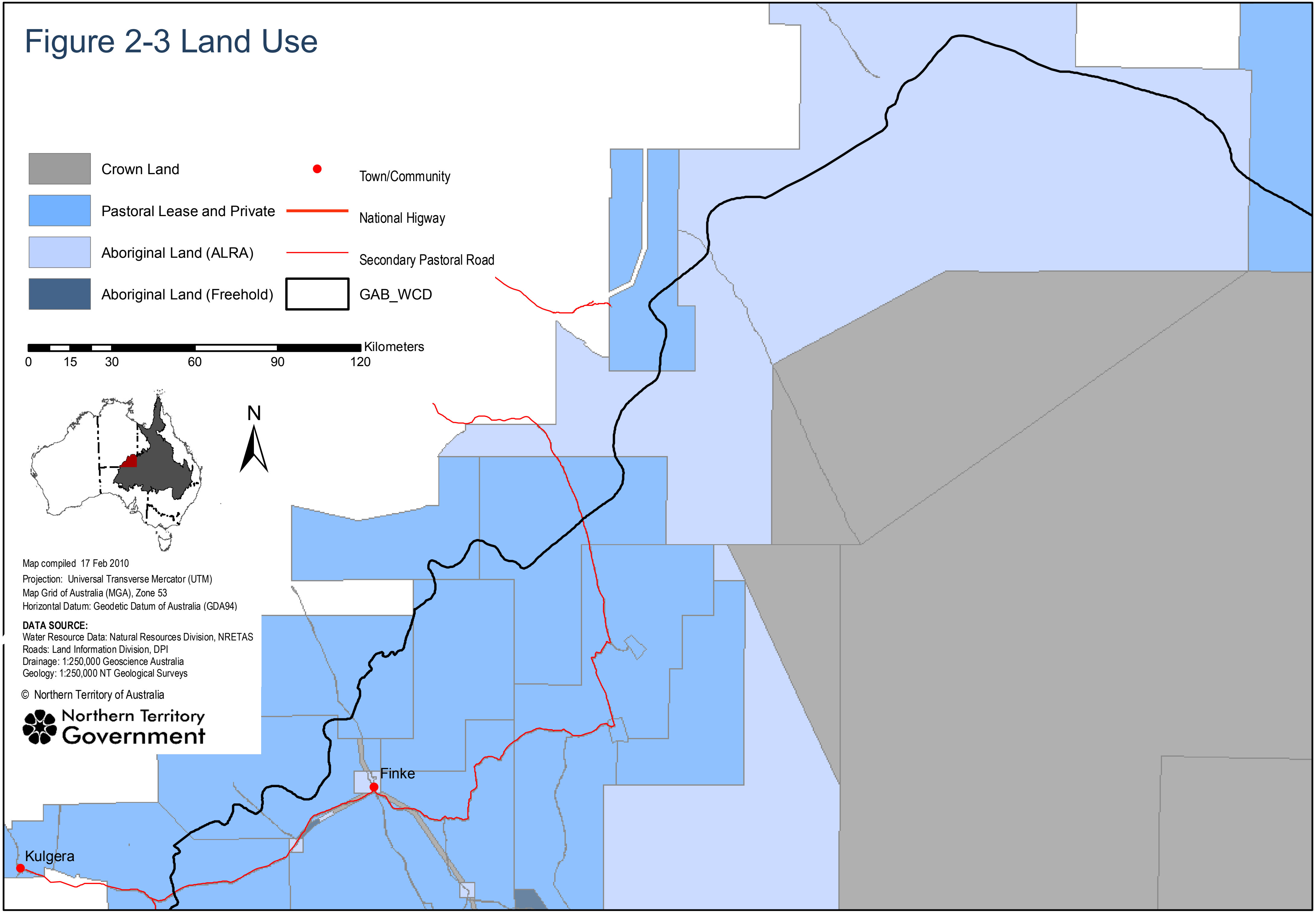
2.3. Landuse

Landuse within the WCD is divided between pastoral, Aboriginal Land Trusts (ALT) and vacant crown land (see **Figure 2-3**). There are two pastoral properties contained entirely within the WCD -New Crown and Andado Station, in addition to small sections of Lilla Creek, Horseshoe Bend and Numery Station. The rearing and grazing of cattle is the principal pastoral enterprise. The WCD includes the Pmere Uplerre, Ingwemrne and Arletherre ALTs. There is also a significant tract of crown land located in the eastern Simpson Desert.

There is a long history of mining exploration within the WCD with a strong focus on oil and gas exploration. There have been several waves of petroleum and gas investigation starting in the 1960s; other key periods occurred in the 1970s, 1980s and the late 2000s. Despite significant exploration there has been no commercial development of oil or gas within the WCD. The focus of recent exploration has shifted to identifying coal seam gas reserves thought to occur in the Permian sequence underlying the GAB. The only recorded mining activity within the WCD occurred at the historical Rumbulara Ochre mines. Located on the south-east margin of the NT GAB, this mine was a source of ochre for the Australian paint industry during the second world war and was operated commercially from 1941 to 1951 (Wells, 1969).

It is estimated that there are 350 people living within the WCD. Apatula Community (also known as Finke Community) is the largest population centre with an estimated 240 inhabitants. The remainder of the population is spread between Aboriginal outstations and pastoral homesteads.

Figure 2-3 Land Use



2.4. Surface water hydrology

The GAB WCD is located in the Lake Eyre surface water basin and contains a number of internally draining watercourses including the Finke, Todd, Hale, Plenty, Hay and Field Rivers and Illogwa, Goyder and Lilla Creeks. The headwaters of all these rivers are located outside the WCD to the north and west of the GAB. It is hypothesised that these rivers originally drained directly to Lake Eyre during the wetter climates experienced in the Oligocene-Miocene (12 -35 Ka) (Craddock et al, 2010). Today, the rivers flow in a broadly south-east direction and terminate in flood-outs in the interior of the Simpson Desert.

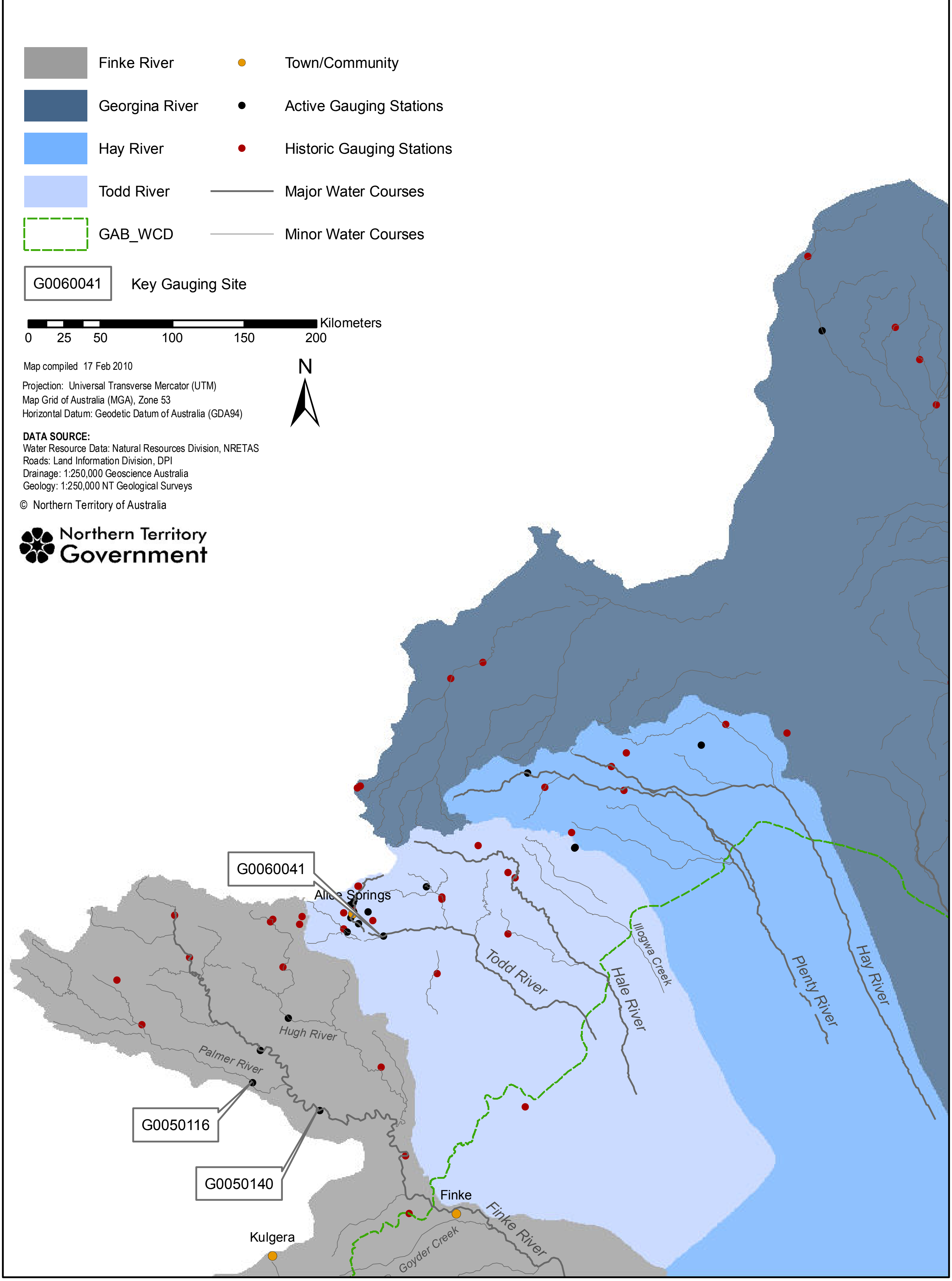
All rivers are unregulated and due to the irregular flow regime are not relied on as a source of stock, domestic or agricultural water supply. However, flooding plays a significant environmental role in maintaining arid ecosystems. At the edge of the basin the GAB aquifer is exposed and where rivers flow across the aquifer outcrop there is potential for direct infiltration of floodwater to the groundwater system. This process is considered to represent the dominant source of recharge to the GAB along its western margin (Radke et al, 2000).

Surface water flow is ephemeral in all watercourses. Flow events are highly episodic and are commonly driven by large rainfall systems associated with the south-easterly movement of monsoonal rain depressions from northern Australia and/or extreme weather caused from cyclonic lows. The availability of gauging data on the rivers is very limited both in terms of spatial coverage and extent of record. **Figure 2-4** shows the existing and historic gauging stations. The most comprehensive data is available for the Todd River near Alice Springs and the Finke River at the Stuart Highway crossing. The hydrographs for these two stations are presented in **Figure 2-5**.

Small flow events occur with annual to bi-annual regularity. The majority are short lived and are driven by very local storm activity. In the case of the Finke River these small events often only result in a section of the river flowing. Large events are anecdotally characterised as those where the river flows simultaneously along its entire length (from Hermannsburg through to the flood-out on Andado). Larger flow events occur around every ten years (1988, 2000, 2010). They often involve multiple flow events (2000, 2010) and can result in the rivers running for weeks as opposed to days for small flow events. Although less frequent, the large flow events in the Finke River are considered to provide a more significant recharge contribution to the GAB aquifer.

All existing gauging stations on the WCD rivers are located in the upper to mid catchments and consequently don't provide an accurate measure of flow duration or size where the rivers cross the GAB recharge zone. The Finke River is a prime example - little quantitative flow data exists around the Finke Community, which is situated in the recharge zone. The closest gauge is located 200km upstream and does not capture the flood contribution of the Hugh River, a major tributary of the Finke River. The lack of stage height and flow data for the reaches of the rivers coincident with the GAB recharge beds represents a key data gap.

Figure 2-4 Surface Water Basins and Gauging Sites



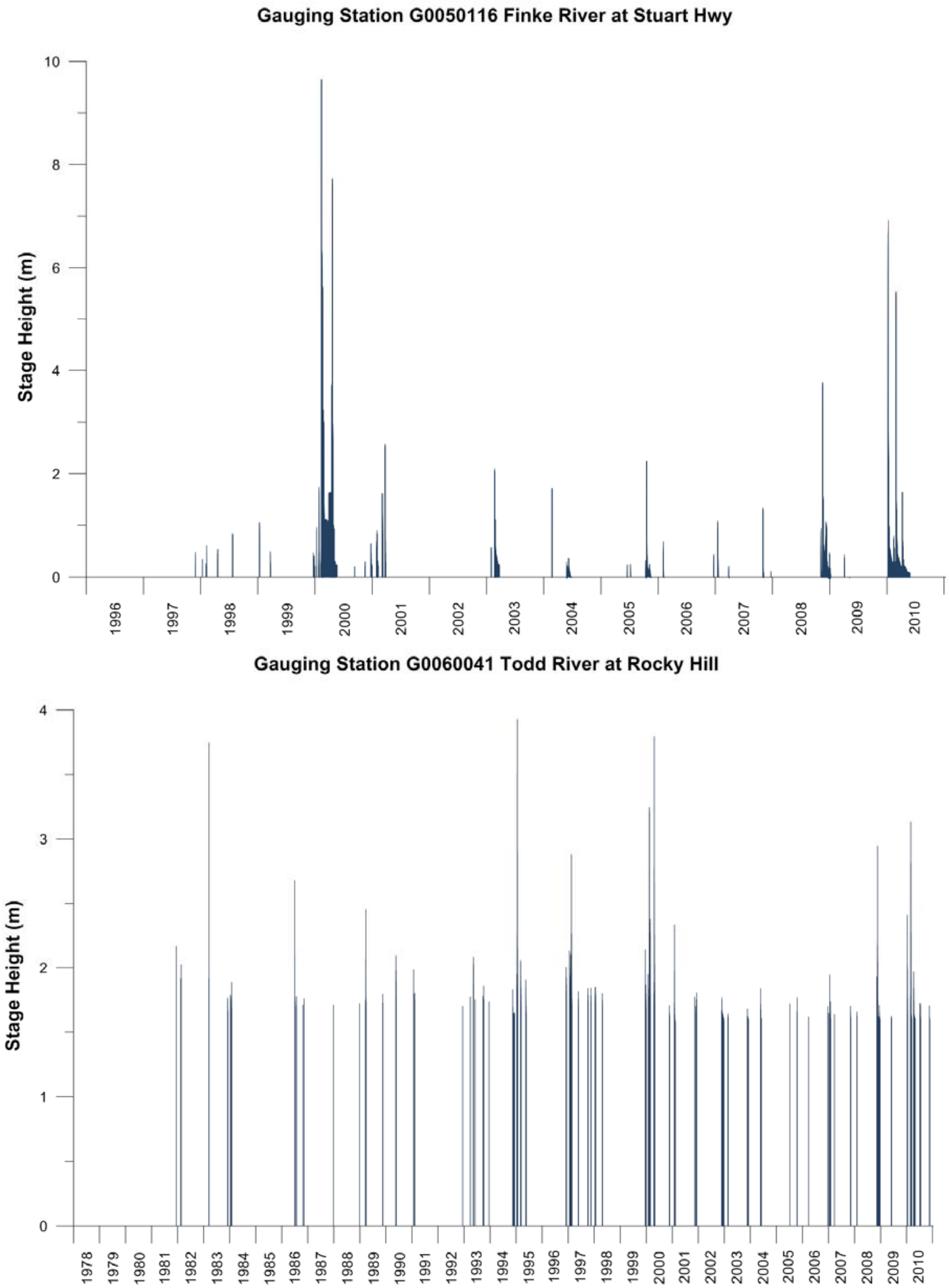


Figure 2-5 Hydrographs for Finke and Todd River Gauging Stations

2.5. Climate

The GAB WCD has an arid climate. It experiences a large temperature range with summer daytime temperatures known to exceed 48°C and winter night-time temperatures dropping below 0°C. At Apatula Community, in the south-west of the WCD, mean monthly minimum temperatures range from 6 to 23°C and mean monthly maximum temperatures from 29 to 38°C.

Annual average rainfall is 200 - 300mm in the north-east of the WCD and grades to less than 150mm in the south (see **Figure 2-8**). Monthly rainfall averages are higher during summer, particularly in the north of the WCD (see BOM Rainfall Station 14214 in **Figure 2-6**). Summer rainfall is driven by the southward migration of tropical low pressure systems that develop off the north coast of Australia. These weather systems produce highly episodic rainfall events capable of delivering significant rainfall over short time periods. This is illustrated in **Figure 2-6**, which shows the daily rainfall totals at New Crown (BOM rainfall station 15600) in the south-west of the WCD for the year 2000. A strong low pressure system produced 184mm of rain in the 48 hour period from the 11th February. This exceeds the annual average rainfall for the area (175 mm) and is over six times the monthly rainfall average for February (28 mm).

Evaporation significantly exceeds rainfall year round (see **Figure 2-6**). Average annual pan evaporation in excess of 3000mm. Due to the large evaporation rates and the bias towards summer rainfall only large rainfall events provide a significant source of recharge water to the GAB aquifer.

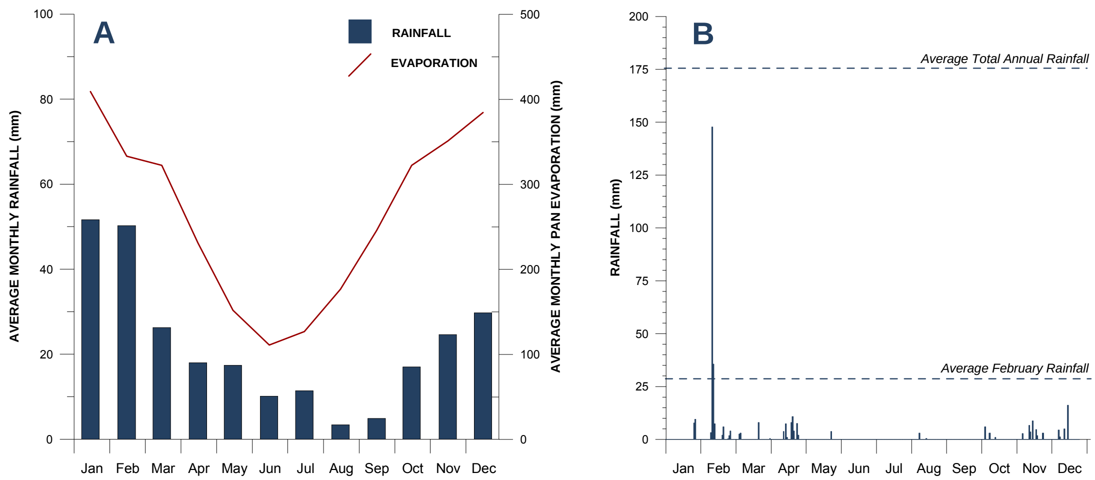


Figure 2-6 A. Average monthly rainfall and potential evaporation, Atula (14214) and B. New Crown (15600) see Figure 2-8 for station locations.

Like much of inland Australia the GAB WCD is subject to long periods of drought. One method of assessing the timing and length of these climate cycles is by graphing the cumulative rainfall departure from normal rainfall (see **Figure 2-7**). A positive gradient indicates a period of above average rainfall, while a negative gradient represents a period of below average rainfall. Prolonged time periods with a negative slope indicate drought conditions. The most significant drought in the rainfall record occurred from the mid 1950's until around 1970. Drought conditions have also prevailed over the last decade (2002 - 2009).

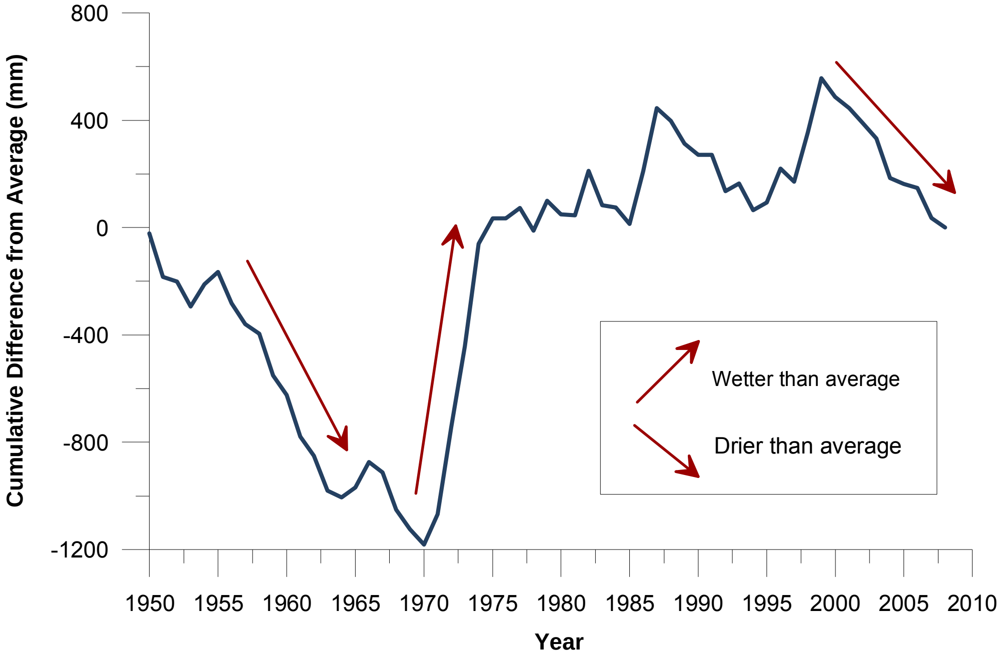
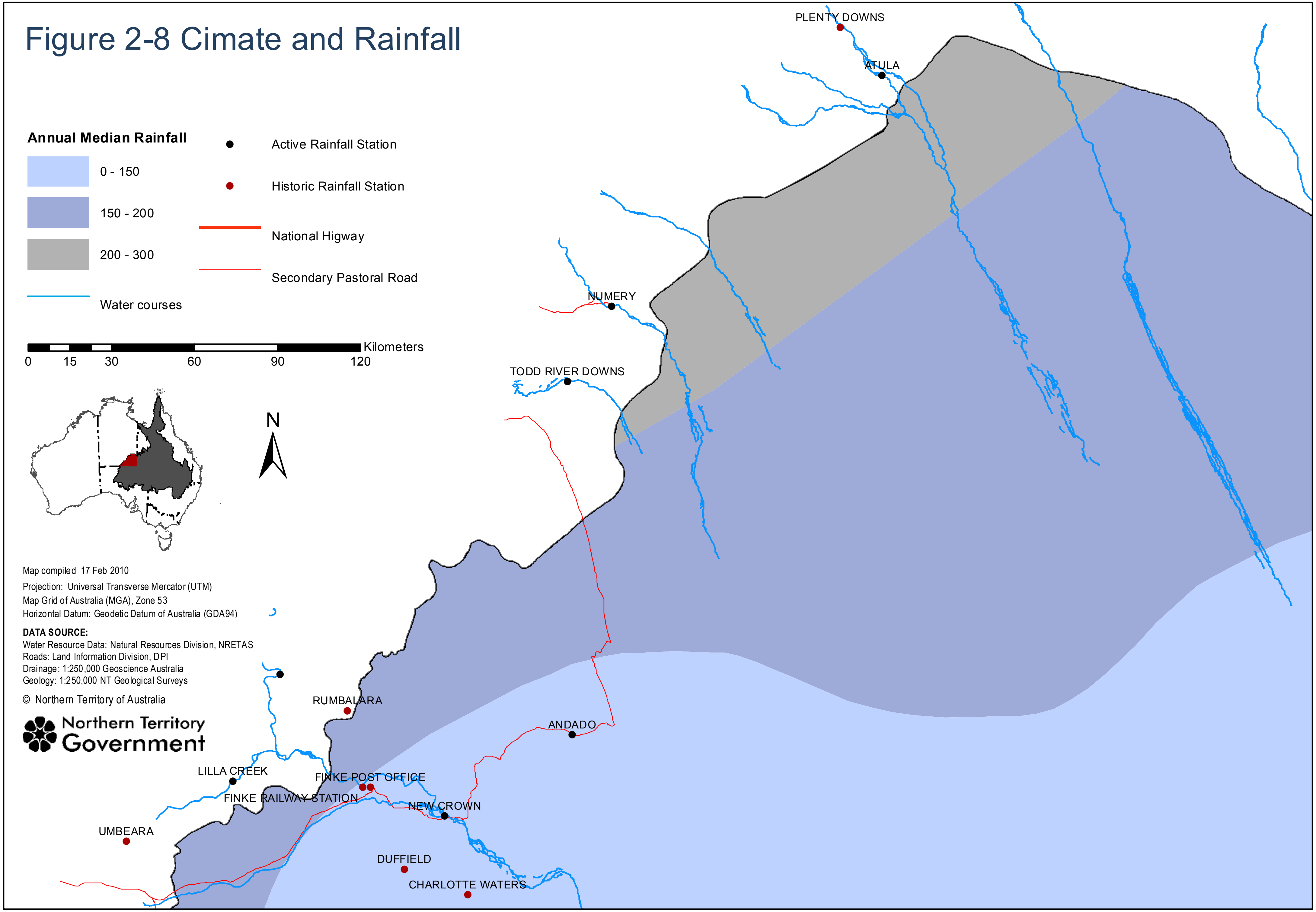


Figure 2-7 Cumulative difference from average rainfall for New Crown (15600)

Figure 2-8 Cimate and Rainfall



Map compiled 17 Feb 2010
Projection: Universal Transverse Mercator (UTM)
Map Grid of Australia (MGA), Zone 53
Horizontal Datum: Geodetic Datum of Australia (GDA94)

DATA SOURCE:
Water Resource Data: Natural Resources Division, NRETAS
Roads: Land Information Division, DPI
Drainage: 1:250,000 Geoscience Australia
Geology: 1:250,000 NT Geological Surveys

Northern Territory Government

2.6. Geology

The Great Artesian Basin is divided into three separate structural and depositional basins – the Eromanga, Carpentaria and Surat - after Mott (1952). The Eromanga Basin, which represents the western GAB, covers a large part of Queensland and is extensive across the Northern Territory and South Australian GAB. The Bureau of Mineral Resources further divided the Eromanga Basin into central, west, north-west and south-west regions (Mond and Yeates, 1973). In the north-western section, the Eromanga Basin consists of sedimentary rocks of Jurassic to Cretaceous age. The Eromanga sequence rests unconformably on the Permian Pedirka Basin in the south-west and west of the WCD, the Triassic Simpson Basin in the south-east and in the north the Cambrian Georgina Basin (**Figure 2-9)**. In several areas along its margin the Eromanga Basin rests directly on Proterozoic Basement. The Eromanga Basin sequence is uniformly overlain by Cenozoic sediments of the Lake Eyre Basin.

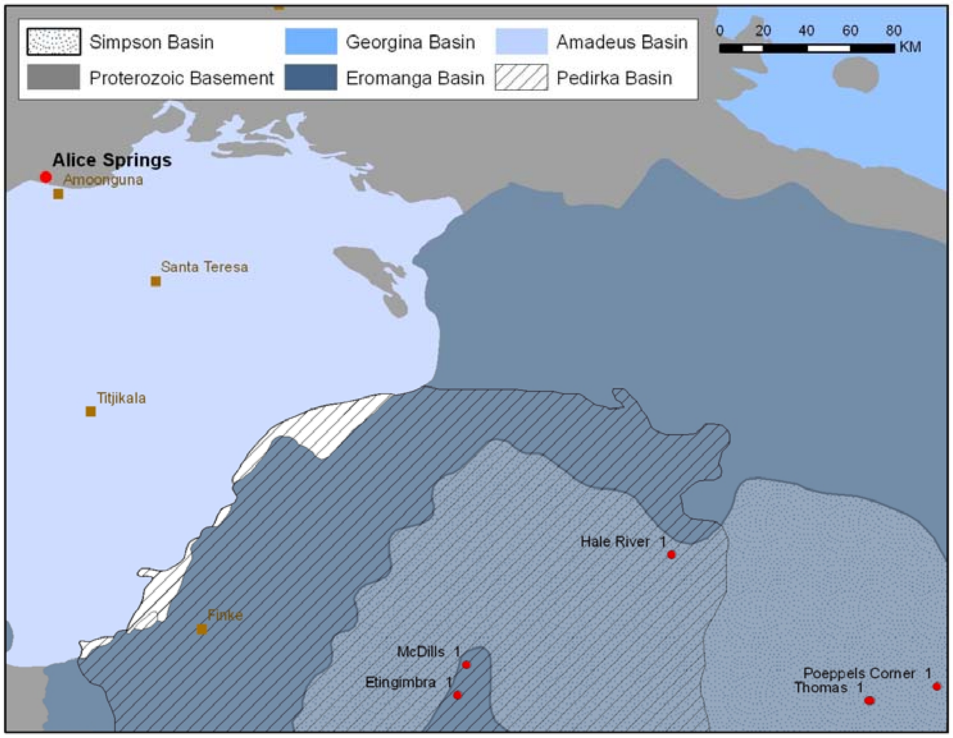


Figure 2-9 Regional Geological Setting (Basin extents)

Within the WCD the Eromanga sequence is thinnest along the margin of the basin where it is present in outcrop. Both the thickness and depth of the basin sediments increase toward the south-east, reaching a maximum recorded thickness of 2100m in oil well Thomas No. 1, located near the NT, SA and QLD border. Outcrop of the Eromanga Basin sediments is largely obscured by Quaternary sand dunes of the Lake Eyre Basin, which has limited the detail of regional structural mapping. Seismic and gravity surveys have identified a number of regional geological structures that influence the geometry of the GAB aquifer and potentially groundwater flow directions. These structural features include the McDills Anticlinal Trend, the Border-Colson Trend, the Eringa Trough, Madigan Trough and Hale River Fault. A more detailed discussion of the tectonic history and the structural development of the Eromanga and Pedirka basins can be found in Middleton (2005), Ambrose (2006) and Questa (1990).

The main geological components of the Eromanga Basin within the WCD are: the Rolling Downs Group, the Cadna-owie Formation, the Algebuckina Sandstone and the Poolowanna Formation. A brief summary of the lithological characteristics and occurrence of these units follows. The surface outcrop and sub-surface expression of the Algebuckina Sandstone and the Rolling Downs Group are shown in **Figure 2-10** and **Figure 2-11** respectively.

2.6.1 Rolling Downs Group

The Rolling Downs Group is a thick sequence of fine grained Cretaceous sediments forming the uppermost geological unit of the Eromanga Basin. These rocks form a continuous, basin wide cap and within the WCD attain a maximum recorded thickness of 1390m at Thomas No 1 oil well. The Rolling Downs Group is present over the entire GAB. Due to this wide geographic distribution the nomenclature of the component units of the Rolling Downs Group is complex. In the Northern Territory section of the Eromanga Basin the Rolling Downs Group consists of the Winton Formation, Allaru Mudstone, Toolebuc Limestone and the Wallumbilla Formation.

Winton Formation

The Winton Formation forms the uppermost unit of the Eromanga Basin. It consists of massive siltstone and claystone interbedded with sandstone and minor coal seams. The claystone is grey, silty, sandy and carbonaceous grading with depth to a light grey, calcareous mudstone (Questa, 1990). There is some variation in the description of the sandstone. Questa (1990) describes them as fine to medium grained quartzose sandstone with a silica/calcite cement. Mond (1973) describes the Winton Formation in the north of the WCD as fine to medium grained lithic sandstone with a clay matrix. The formation is extensive across the WCD. It outcrops on the Simpson Desert North, Simpson Desert South and McDills 1:250 000 Mapsheets. It reaches a maximum recorded thickness of 623 metres in Thomas No 1 oil well and exceeds 400m in thickness across much of the WCD (Questa, 1990).

Allaru Mudstone

The Allaru Mudstone comprises a light to medium grey, carbonaceous and silty shale with common siltstone and minor sandstone beds (Questa, 1990). The Allaru Mudstone outcrops on the Hay River 1:250 000 mapsheet in the north of the WCD. The formation reaches a maximum recorded thickness of 580m in the Hale River oil exploration bore. The Oodnadatta Formation is the time equivalent of the Allaru Mudstone in South Australia.

Toolebuc Limestone

The Toolebuc Limestone comprises a grey shale and greyish brown limestone. It is not known to outcrop in the WCD but has been identified subsurface in several oil exploration bores. The recorded thickness of the unit ranges from 30 - 71m. The Toolebuc Limestone produces very high counts on gamma-ray logs and is recognised as a widespread marker bed distinguishing the Allaru Mudstone from the Wallumbilla Formation (Mond, 1974).

Wallumbilla Formation (Rumbulara Shale)

Wallumbilla Formation consists of grey mudstone and siltstone with thin interbedded fine grained sandstone, it is glauconitic and calcareous in part (Yeates, 1974). This unit attains a maximum recorded thickness of 237m at Thomas No 1 oil well. The Wallumbilla Formation is known as the Bulldog Shale in South Australia and the Rumbulara Shale in the Northern Territory. Many of the sedimentary rocks mapped on McDills, Hale River, Hay River and Finke Sheets as Rumbulara Shale actually belong to the greater Rolling Downs Group (Mond, 1973). Early mapping and logging of water bores did not make the distinction between the various components of the Rolling Downs Group but rather grouped them all as the Rumbulara Shale. Divisions within the Rolling Downs Group have developed as more detailed stratigraphic information came to hand as a result of oil and gas exploration. In order to avoid confusion in this report the Wallumbilla Formation is adopted as the naming convention for the bottom member of the Rolling Downs Group.

2.6.2 Cadna-owie Formation

The Cadna-owie Formation, also referred to as the transition beds, is a thin sandstone, mudstone and shale unit that marks the transition from the terrestrial sediments of the Algebuckina Sandstone to the marine sediments of the Rolling Downs Group. It consists of fine to medium grained quartz sandstone with siltstone and minor mudstone increasing in abundance toward the formation base. In the upper part of the formation the sandstone consists of well sorted quartzite with minor pebbles, shell fragments, glauconite and a carbonate cement (Questa, 1990). The basal sands in the Cadna-owie Formation have a lower gamma-ray count than the sandstones of the underlying Algebuckina Sandstone. The unit ranges in thickness from 15 - 80m and is commonly in the order of 30m thick.

2.6.3 Algebuckina Sandstone

The Algebuckina Sandstone is a Jurassic to late Cretaceous sandstone that is laterally continuous across the WCD. The formation is locally referred to as the De Souza Sandstone in the Finke region after Sullivan and Opik (1951), its time equivalent in the north of the WCD is the Longsight Sandstone (Mond, 1973) and in Queensland the Hooray Sandstone (Senior *et al*., 1978). The name Algebuckina Sandstone has become the accepted stratigraphic term for the early Jurassic Sandstone unit in oil and gas exploration within the Northern Territory and is adopted for this report.

The formation comprises a fine to medium grained, quartzose sandstone that is cemented and silicified. It contains lenses of conglomeritic sandstone containing quartz and quartzite pebbles and minor lithic fragments. Thin shale and siltstone beds are sometimes encountered but these are minor and are not laterally continuous. Subsurface, the Algebuckina Sandstone is white to light grey - in outcrop it weathers to a brown-red colour and exhibits distinct cross-bedding. The formation reaches a maximum recorded thickness of 637m in Thomas No. 1 oil exploration well in the south-east of the NT.

The Algebuckina Sandstone outcrops on the western margin of the WCD and is present at the surface on the Finke, Illogwa Creek, Hale River and Tobermory 1:250 000 geological mapsheets. In many areas along the western edge of the Eromanga Basin weathering has isolated areas of the Algebuckina Sandstone creating disconnected islands of outcrop.

2.6.4 Poolowanna Formation

The Poolowanna Formation represents the basal unit of the Eromanga Basin. This Jurassic aged formation consists of coarse to medium grained quartz sandstone interbedded with grey, siliceous siltstone, dark grey to brown carbonaceous shale and coal beds. The top of the formation is marked by a distinctive black, carbonaceous coaly shale. Typically fine grained sediments are predominant in the top 25% of the formation, which becomes progressively sandier with depth (Questa, 1990). The Poolowanna Formation is sandier towards the western margin of the basin where it is commonly included as part of the Algebuckina Sandstone. The Poolowanna Formation attains a maximum recorded thickness of 194m in Poepells Corner Oil Exploration bore. It is not present in outcrop in the Northern Territory and is absent in the western most oil exploration wells (i.e. McDills, Etimingbra, Hale River).

2.6.5 Peera Peera, Crown Point and Purni Formations

In the east and south of the WCD the Eromanga Basin overlies the Triassic aged Simpson Basin. In this area the Poolowanna Formation rests on the Peera Peera Formation, which consists of siliceous, carbonaceous shales with thinly bedded fine grained sandstones.

In the west of the WCD the Eromanga Basin overlies the Permian Pedirka Basin. On the margin of the basin the Poolowanna Formation rests on the glacial sediments of the Crown Point Formation. Away from the margin of the basin the Poolowanna Formation overlies interbedded sandstone, siltstone, shale and coal of the Purni Formation. Detailed discussion of the Triassic and Permian sequences can be found in Questa (1990).

Figure 2-10 CROSS SECTION A-B-C

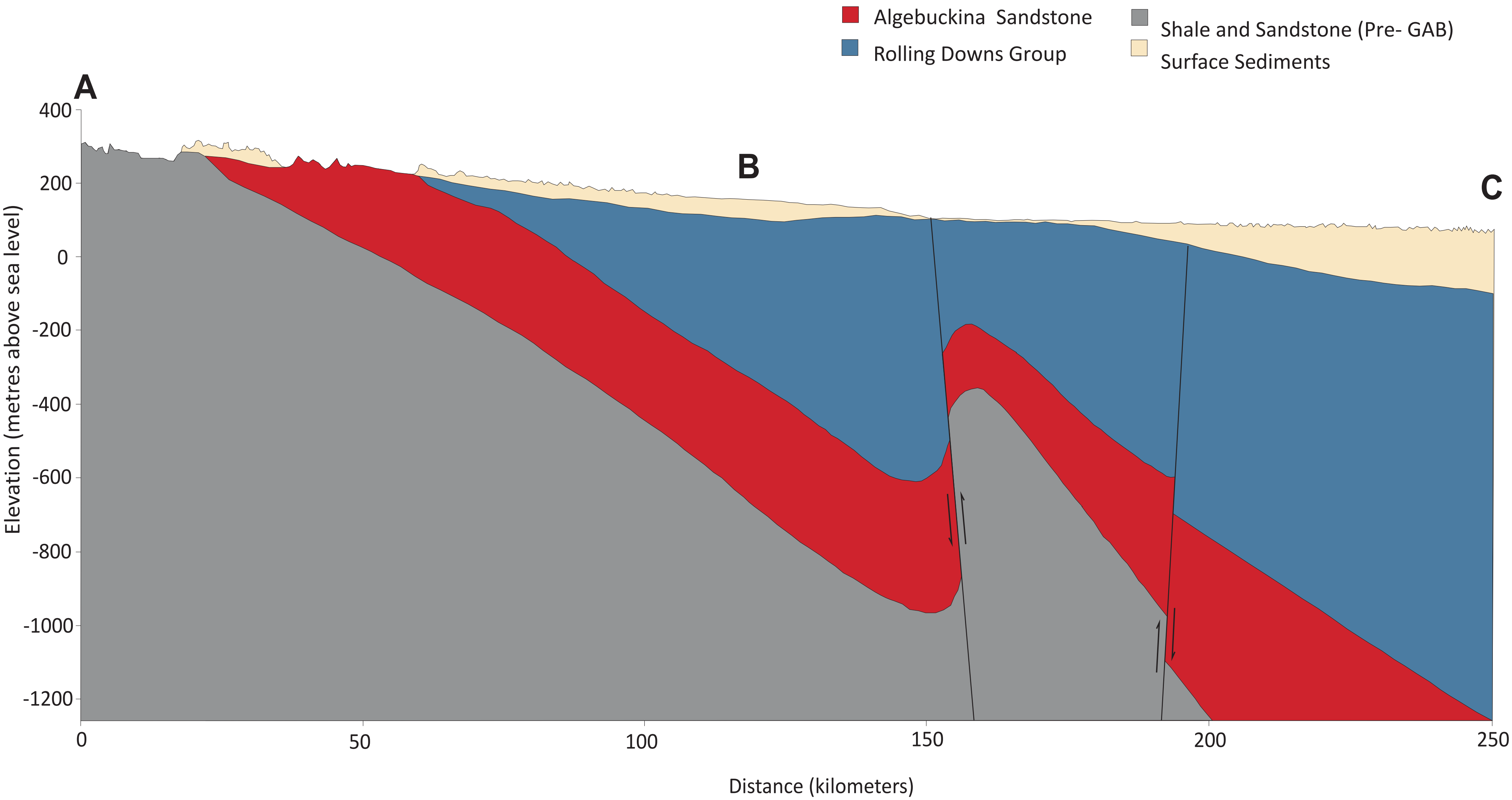
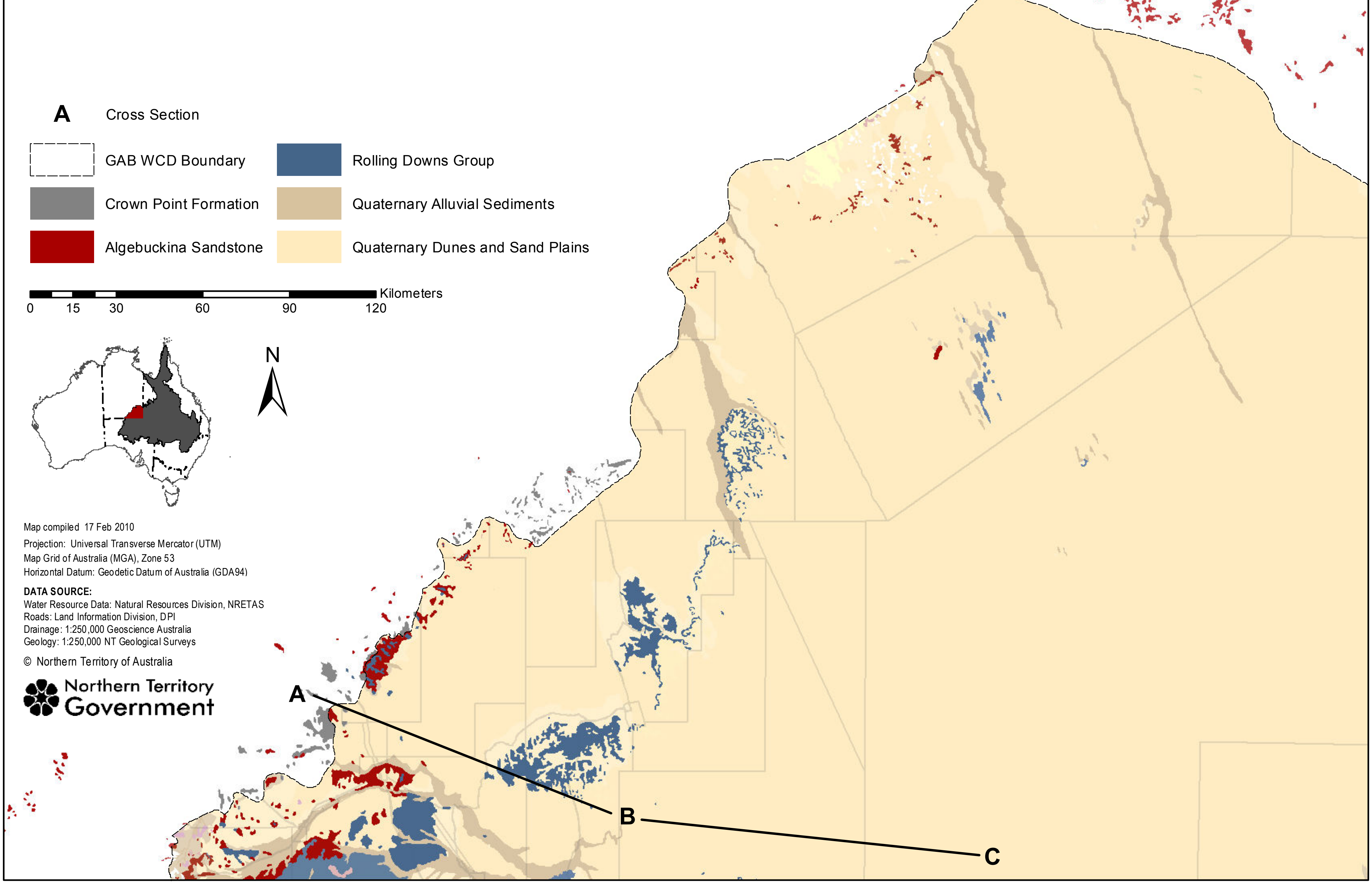


Figure 2-11 Surface Geology



2.7. Previous Work

The first published investigation of groundwater resources in the NT portion of the GAB was undertaken by Ward (1926) which assessed the prospectivity of groundwater supplies along the stock route between Alice Springs and Charlotte Waters Telegraph Station. Ward produced a second study in 1946 discussing groundwater quality and availability in the southern NT. A brief investigation undertaken by the Water Resources Branch in Alice Springs in 1962 discussed the availability of groundwater on Andado Station (Rochow, 1962). This was followed by a more detailed study by Rochow in 1965 documenting the geology and occurrence of groundwater on the Finke 1:250K mapsheet. Between 1960 and 1975 the Bureau of Mineral Resources undertook an extensive geophysical logging program of water bores across the GAB and included a number of pastoral bores in the NT, mostly located on New Crown and Andado Stations. This work was compiled, digitised and published by AGSO (Habermehl, 2001).

In 1990, Power and Water Authority (PAWA) published a water source and bore field review for Finke community (Berry, 1990). The work led to the replacement of several water supply bores by PAWA at Finke Community. The drilling results are documented in a bore completion report by Matthews (1992). PAWA, at the request of the Department of Primary Industries and Fisheries (DPI&F) conducted a study to assess the availability and accessibility of artesian water from the GAB aquifer underlying Andado Station (Rooke, 1991). The first comprehensive review of the hydrogeology of the NT portion of the GAB was undertaken by Matthews (1995). Water Resources completed a groundwater study the following year (Matthews, 1996), which involved groundwater sampling of GAB stock bores, the installation of two deep confined monitoring bores and a suite of chemical and isotopic analysis of groundwater (^{2}H, ^{18}O, ^{14}C, ^{36}Cl). The NT GAB has been included in several basin wide GAB studies, the most comprehensive published investigation was undertaken by the Bureau of Rural Services (BRS) in the late 1990s (Radke *et al.,* 2000) and included a round of groundwater sampling concentrating on the chemical and isotopic characterisation of the Cadna-Owie/Hooray sandstone aquifer (referred to in this report as the J aquifer). The field programs for both the Matthews (1996) and Radke *et al.,* (2000) investigations focused on New Crown and Andado Stations, located in the south-west of the NT GAB. To date, no published groundwater investigation work covers the northern section of the basin.

Between 1999 and 2003 Water Resources Division (WRD) undertook the rehabilitation of the three uncontrolled artesian bores in the NT portion of the GAB: Anacoora (RN000577), McDills (RN005028) and Dakota Bore (RN012431) - results of this program are contained in an unpublished internal DIPE (Department of Infrastructure, Planning and Environment) report (Humphreys and Kunde, 2004). WRD has drilled a number of groundwater investigation bores along the margin of the GAB over the last two decades. One of the more notable bores was a 513m deep hole drilled on an Andado Excision; Read (2003) documents the drilling program for this bore and includes downhole geophysics and a review of surrounding deep groundwater bores. In 2007, a review of the monitoring network in the GAB was undertaken by WRD (Wischusen, 2007).

3. Hydrogeology

The Great Artesian Basin consists of a series of discrete, laterally extensive sandstone aquifers separated by mudstone and siltstone aquitards. To simplify the description and categorisation of these aquifer units Siedel (1980), and Habermehl (1980), proposed two composite aquifer sequences: the J Aquifer containing the Cadna-owie, Hooray, Adori, Brikhead, Hutton, Precipice and Clematis Aquifers, and the K Aquifer containing aquifers of the younger Winton and Mackunda Formations.

Within the WCD, the principal groundwater resource is hosted in the Algebuckina Sandstone, which forms part of the J aquifer. Groundwater is also encountered in sandstone interbeds within the Winton Formation and the Wallumbilla Formation (K aquifer). However, within the NT this groundwater is generally of poor quality and is not laterally continuous. The occurrence of groundwater in the K aquifer is discussed further in **Section 3.2.2**. Minor groundwater supplies have also been identified in shallow Quaternary deposits along present day drainage lines, within the Permian Crown Point Formation and the Devonian Finke Group. All these aquifer systems occur at least partially within the geographic boundaries of the WCD but are not part of the GAB aquifer sequence. Unless otherwise stated references to the GAB aquifer or groundwater resources in this report refer to the J Aquifer.

3.1. J Aquifer

Within the WCD the J Aquifer is comprised of the Cadna-owie Formation, the Algebuckina Sandstone (known locally as the De Souza Sandstone) and the Poolowanna Formation - the latter is only present towards the centre of the basin. The J Aquifer is the only regionally extensive water resource in the GAB WCD. It outcrops along the western and north-western margin of the WCD. The J Aquifer is unsaturated on the edges of the WCD, becoming saturated and confined to the south-east, then confined and sub-artesian, and finally confined and artesian. The approximate extents of these hydrogeological boundaries are shown in **Figure 3-1**.

The J Aquifer is a porous media sandstone aquifer. Although the sandstone does not appear significantly fractured or jointed in outcrop, recent pumping test results in the unconfined section of the aquifer revealed dual porosity behaviour.

Most bores accessing groundwater from the J aquifer are for stock or domestic use and commonly only penetrate the top few metres of the aquifer. Yields from stock bores are generally reported as being in the order of 1 - 5 L/s, though this tends to be more an indication of water requirement rather than the true yield potential of the aquifer. Appropriately constructed bores targeting the J aquifer are capable of relatively high yields. Before rehabilitation, McDills (a failed oil exploration well that was partially converted to a water bore) was free flowing at an estimated 120 L/s (Humphreys and Kunde, 2004). In the unconfined portion of the aquifer Water Resources has recently tested a bore capable of yields over 30 L/s.

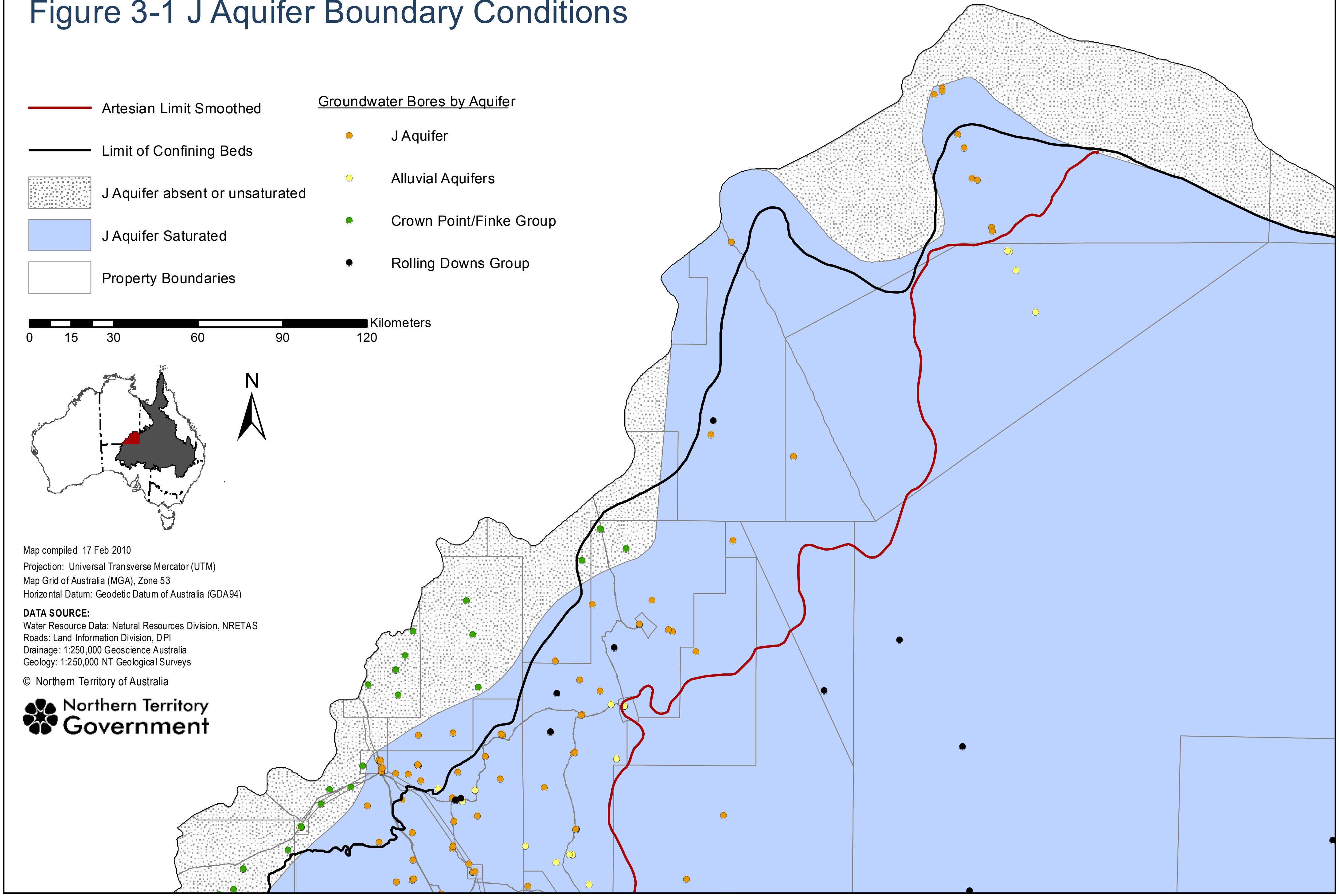
The J aquifer has reported porosities of between 21 – 24% recorded from sidewall cuttings and logs from Poepells Corner Well Completion Report (ARCO, 1985). Regionally, Radke (2000) reports porosities in the J Aquifer as between 10 and 29% with an average porosity of

23%. Generally, the porosity decreases as the burial depth of the aquifer increases (Radke, 2000).

There is limited information available on aquifer transmissivity and/or hydraulic conductivity in the WCD. Matthews (1995) states that transmissivity of the De Souza Sandstone aquifer can range from ten to several hundred m^2/day. This is probably an underestimate as preliminary data from a recent pumping test near Finke Community suggests a transmissivity in the order of several thousand m^2/day. Data loggers tracking surface water and groundwater levels after flood events in late 2010 estimated hydraulic conductivity to be 10m/day and specific yield 15 to 20% in the unconfined portion of the aquifer around Finke Community (refer Section 3.5.2). There is no data available on specific storage or storage coefficients within the confined portion of the NT GAB. Habermehl (1980) reports an average storage coefficient of 10^{-5} for the regional GAB aquifer.

The absence of confirmed hydraulic conductivity, transmissivity and storage coefficients through traditional test pumping methods represents a key information gap for this assessment. Aquifer parameters are critical for any meaningful assessment of recharge, groundwater residence time and in any attempt to predict the impact of potential future groundwater extraction. Assessments made within this report rely on text book estimates of storage parameters and consequently have a large margin for error.

Figure 3-1 J Aquifer Boundary Conditions



3.2. Other Groundwater Resources

3.2.1 Quaternary and Tertiary Aquifers

Groundwater resources are present in Quaternary and Tertiary aquifers connected to existing water courses in the WCD. These aquifers are not regionally extensive but rather appear to be restricted to the areas around the present day river channels and surface water drainage sites (i.e. swamps). Along some systems such as the Finke River, alluvial aquifers can extend for several kilometres either side of the current day channel. These aquifers were developed over time by the migration, erosion and deposition of sediments by these rivers.

Water quality is variable - in some instances groundwater in these systems is potable but it can also be highly saline. This is illustrated by three shallow bores WRD installed near New Crown homestead in 2009. RN018353, located in the alluvial aquifer on the edge of the Finke River has a salinity of 2300μs/cm. RN018355, located at a similar depth 2km further west has four times the groundwater salinity at 9500μs/cm

The availability and quality of groundwater in the alluvial aquifers is strongly influenced by infrequent flow events in the rivers which represents the principal recharge mechanism to these aquifers. The alluvial aquifers may also provide a conduit for flood water to recharge the J aquifer, which is thought to occur in some of the northern river systems (i.e. the Plenty River and Illogwa Creek). No information is available on aquifer parameters or reliable bore yield data for the alluvial aquifers in the WCD.

3.2.2 Rolling Downs Group

Groundwater is present in sandstone interbeds within the Rolling Downs Group. This groundwater is typically highly saline - with a TDS up to 9,450mg/l in a roads bore recently drilled for Central Petroleum during a gas exploration program. Groundwater of poor quality also occurs at the base of the Wallumbilla Formation in the Cadna-owie Formation (see Matthews 1995 for an detailed description of this phenomenon). There are several recorded instances of inadequate bore construction leading to inter-aquifer leakage between groundwater at the base of the Wallumbilla Formation and the J aquifer. The most common scenario is the failure to cement casing in order to isolate aquifers within and at the base of the Wallumbilla Formation - this represents a threat to water quality in J aquifer and should be addressed in bore construction requirements for the WAP. Poor bore construction makes it difficult to confidently assess groundwater quality patterns within the J aquifer (this is discussed further in the **Section 3.3**).

Groundwater resources within the Rolling Downs Group are generally too saline for human consumption or stock watering. Most groundwater extracted from these aquifers in the WCD has been used for road construction. Groundwater from the sandstone and shale beds at the base of the Wallumbilla Formation is generally not potable for human consumption but is of a quality suitable for stock watering.

3.2.3 Crown Point Formation and Finke Group Aquifers

Groundwater is present in both the Crown Point Formation and the Finke Group. Both of these units underlie the J aquifer along the western margin of the WCD. Little information is available regarding groundwater and aquifer properties in the Crown Point Formation and most data occurs at the edge of the GAB basin where the J aquifer becomes unsaturated. In these areas it appears that groundwater in the Crown Point Formation may flow laterally into the J aquifer.

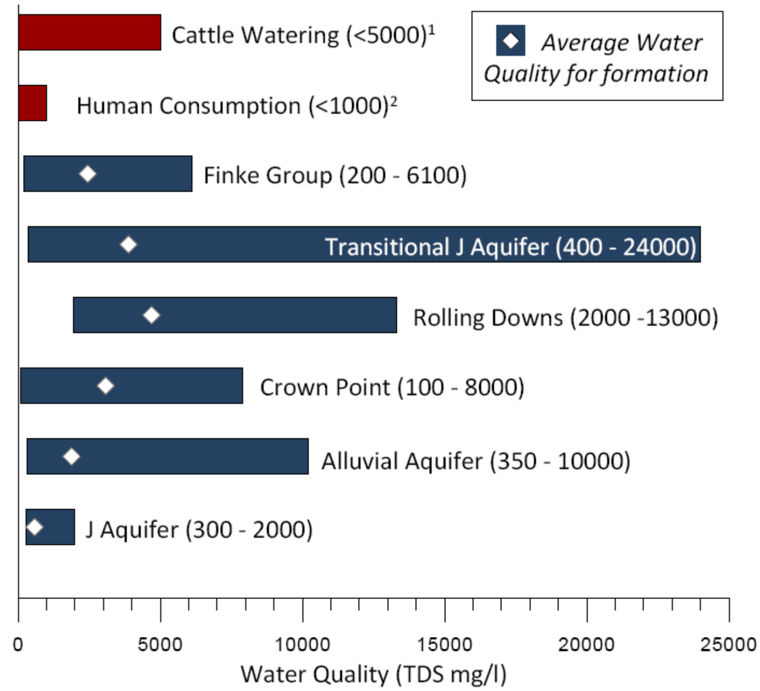
Generally water resources in the Crown Point Formation are of a higher salinity compared with the J aquifer - while generally still suitable for stock watering the resource is not potable for human consumption. The formation consists of a greater proportion of fine-grained sediments and as a consequence the availability of the groundwater resource in this formation is less reliable than the J aquifer.

3.3. Water Quality

Water quality data for this assessment has been drawn from the analyses of mandatory grab samples taken at the time of drilling and also from water quality benchmarking of pastoral bores which has been undertaken by the WRD intermittently over the last three decades. Water quality data is available in the bore statements and can be accessed online through the NRETAS maps data portal (http://www.lrm.nt.gov.au/nretasmaps). In this report bores are categorised into the aquifer units discussed in **Section 3.1** and **3.2** with an additional "transitional" group being added. The transitional aquifer represents bores that are either completed in the top few metres of the J aquifer or are not constructed to adequately isolate the J aquifer from the ingress of poorer quality water from the overlying Rolling Downs Group.

The best quality groundwater in the WCD occurs in the J aquifer; well constructed bores screening this formation report an average Total Dissolved Solids (TDS) of 580mg/l and range between 285 and 2000mg/l. The aquifer is unique in that it is the only reliable potable water supply in the region. Spatial patterns in groundwater quality within the J aquifer are complicated by poor bore construction (see below). However, groundwater quality is clearly better surrounding the Finke and Plenty Rivers as a result of active recharge. Water quality is more variable and generally of much poorer quality in the Rolling Downs Group and the Transitional Group - the average TDS for groundwater from these units is 4690 and 3900mg/L respectively, and sits at the upper end of the water quality range that livestock will tolerate - 5,000mg/l (see **Figure 3-2**). Water quality in the Quaternary and Tertiary aquifers ranges from 340 to 10,000mg/l with an average TDS of 1,900mg/l. Better quality water in this aquifer can be found adjacent to active river systems, however, the quality of the supply can be unreliable being dependant on the freshening influence of flood events in these rivers.

Bores that tap the first groundwater strike in the J aquifer are of noticeably poorer quality than those bores that are drilled deeper into the aquifer. This phenomenon has been discussed in detail in Matthews (1995, 1996) and is illustrated in **Figure 3-3**, which shows a trilinear Piper diagram plotting the relative concentrations of major and minor ions in groundwater bores. Groundwater samples from the Rolling Downs Group (green diamonds) and the transitional bores (red diamonds) broadly cluster together closer to the sodium and chloride end members. Groundwater from deeper in the J aquifer or where the J aquifer is unconfined have a distinctly different ionic signature, with a higher relative proportion of calcium and bicarbonate.



1. Guidelines for Beef Cattle without any loss of production or decline in health (ANZECC AND ARMCANZ, 2000)

2. ADWG (2004)

Figure 3-2 Groundwater quality range in the J aquifer and other aquifers in the WCD

These results suggest that the poorer quality groundwater observed in some areas of the J aquifer may be directly related to bore construction. Bores which are not constructed beyond the Rolling Downs Group/J Aquifer transition or which do not effectively isolate groundwater from within the Rolling Downs Group may result in poorer quality water that is not suitable for human consumption or in extreme cases stock watering. Poorly constructed bores also represent a localised threat to the groundwater quality of the J aquifer as they provide a conduit for inter aquifer leakage. It is recommended that in the confined portion of the J aquifer bore construction requirements for the GAB WCD should ensure isolation of groundwater in the Rolling Downs Group. Practically, this should involve pressure cementing casing to shield the steel from corrosion and to prevent inter-aquifer flow through the bore annulus. Consideration should be given to requiring the use of inert casing and sulphate resistant cement where high levels of sulphate have been identified in the Rolling Downs and/or the J aquifer.

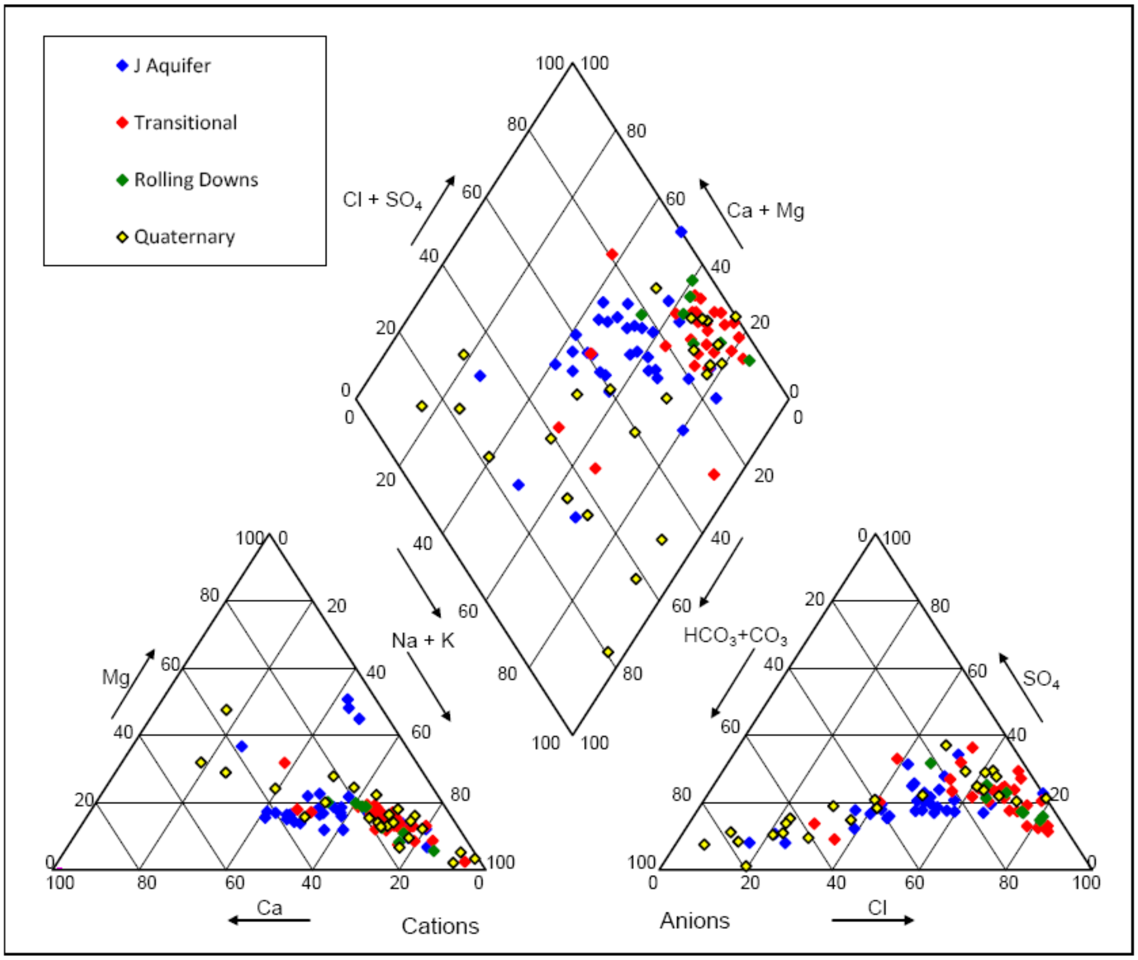


Figure 3-3 Trilinear piper diagram for GAB WCD aquifers

3.4. Potentiometry and Groundwater Flow Directions

Water level data has been used to construct a potentiometric surface for the J aquifer (see **Figure 3-4**). Water levels have been taken from several different sources including estimates from bores at the time of drilling, readings from DLRM bore audit programs and water level data from GAB monitoring bores. To assist with the interpolation of the surface at the edges of the WCD, the NT data set has been complemented by additional water level data from J aquifer bores in SA and QLD.

Due to the absence of regular water level readings this is a time composite water level surface. Where one or more readings exist for a bore the most recent reading has been selected. Erroneous water level readings have been omitted. Each bore has been assigned a land surface elevation from the national SRTM V2 Digital Elevation Model (DEM), which was used to convert the standing water level - measured in metres below the land surface - to a reduced water level (metres above Australian Height Datum) - further detail on the SRTM DEM can be found at http://www.ga.gov.au/. The reduced water levels have been density corrected for temperature, depth and salinity using a method described in Post *et al,.* (2007).

There is some uncertainty in the accuracy of the surface at a local scale flowing from the combination of water level readings from different years and seasons. There is also an error associated with the accuracy of the SRTM DEM, however, this is not significant against the known scale of elevation changes. Given the large size and storage capacity of the GAB the potentiometric surface is considered a reasonable representation of the regional groundwater flow pattern in the J aquifer.

Regionally, groundwater in the J aquifer flows in a south-east direction away from the edges of the GAB and toward the SA and QLD border (see Figure 3-4). Regional groundwater gradients are very low, being in the order of 0.0003. Existing water level data is concentrated in a relatively small area along the western and north-western margin of the GAB. In the eastern half of the WCD there are no water level measurements for the J aquifer. Groundwater flow directions in this area are inferred from water levels in bores and springs across the state borders. Groundwater flow directions in these areas should be viewed with a low level of confidence. A groundwater mound is present under the Finke River where it flows through Apatula (Finke) Community. Groundwater levels in this area are 10 – 15 metres higher than regional water levels in the aquifer and clearly indicate a zone of enhanced recharge around the Finke River. Local groundwater gradients around Apatula are in the order of 0.0008 (approximately two to three times higher than the regional gradient) Elevated groundwater levels also occur around Illogwa Creek and the Plenty River suggesting recharge may also be occurring through sections of these rivers, although the density of data points is too low to be conclusive.

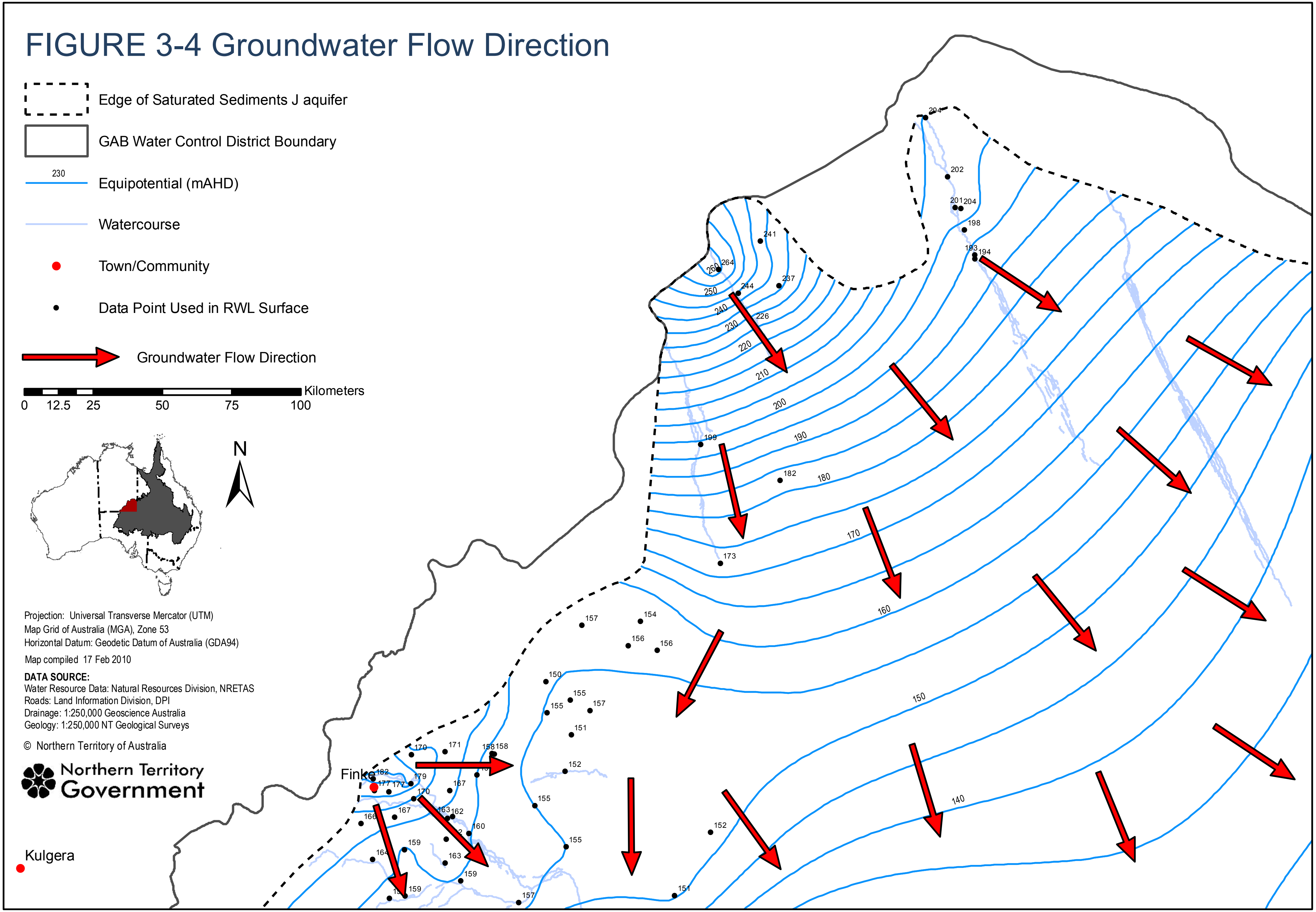


FIGURE 3-4 Groundwater Flow Direction
Edge of Saturated Sediments J aquifer
GAB Water Control District Boundary
Equipotential (mAHD)
Watercourse
Town/Community
Data Point Used in RWL Surface
Groundwater Flow Direction
Kilometers
0 12.5 25 50 75 100
N
Finke
Kulgera
Projection: Universal Transverse Mercator (UTM)
Map Grid of Australia (MGA), Zone 53
Horizontal Datum: Geodetic Datum of Australia (GDA94)
Map compiled 17 Feb 2010
DATA SOURCE:
Water Resource Data: Natural Resources Division, NRETAS
Roads: Land Information Division, DPI
Drainage: 1:250,000 Geoscience Australia
Geology: 1:250,000 NT Geological Surveys
© Northern Territory of Australia
Northern Territory Government

3.5. Recharge

There are two recharge mechanisms that are considered to replenish groundwater to the J aquifer: direct infiltration and recharge through flooding in ephemeral rivers. A discussion of the relative importance of these two mechanisms follows.

3.5.1 Direct Infiltration

Recharge through direct infiltration refers to water that enters the J aquifer through the deep drainage of rainfall. This can occur either directly where rain falls on the outcropping aquifer or indirectly where rain falls on porous surface sediments (e.g. Aeolian dune sands) that overlie the J aquifer. In this instance groundwater seeps down through the overlying sediments and then infiltrates into the J aquifer.

Recharge rates through direct and indirect infiltration to the J aquifer are thought to be almost negligible. This is primarily due to the arid climate. Rainfall rates are very low (<150mm/year in some areas) and evaporation rates are extremely high (>3000mm/year). Generally evaporation and transpiration losses are thought to inhibit any significant diffuse recharge from rainfall. This is supported by Love et al (2000) who found that diffuse recharge rates were in the order of 0.3mm/year along the western GAB margin in South Australia. There have been no studies investigating recharge rates through direct infiltration in the WCD region. For the purpose of this assessment it is assumed that direct infiltration does not contribute a significant volume of recharge to the J aquifer in the Northern Territory.

3.5.2 Ephemeral River Recharge

Ephemeral river recharge describes the infiltration of water through the base of desert rivers into the J aquifer during episodic flood events. Despite having an arid climate the region is prone to extreme weather events (see **Figure 2-6**). Large low pressure systems can deliver intense rainfall, driving floods in the surface water system. Where drainage lines cross the margins of the J aquifer in outcrop, potential exists for direct infiltration of flood water into the aquifer. This process only operates on the edge of the GAB where the J aquifer is unconfined. Away from the basin margin low permeability shales of the Rolling Downs Group isolate the J aquifer from surface water.

Within the WCD ephemeral river recharge is known to operate along the Finke River and is thought to also contribute recharge along the Plenty and Hale Rivers, in addition to Illogwa and Goyder Creek. The Finke River is the only river with conclusive data and has been selected as a case study to base estimates of ephemeral river recharge for the water allocation plan.

Case Study - Ephemeral River Recharge along the Finke River

A review of groundwater chemistry in bores around the Finke River reveals elevated Carbon-14 (^{14}C) concentrations close to the river channel and a decrease in ^{14}C concentrations down flow path away from the Finke River (see **Figure 3-5**). ^{14}C is a radionuclide with a known decay rate and is commonly used as a tool in groundwater investigations to estimate groundwater residence time. ^{14}C concentrations in groundwater close to the Finke River approach current day atmospheric concentrations of 100 pmC (Percent Modern Carbon) and suggest short residence times. ^{14}C concentrations decrease uniformly as distance from the Finke River increases indicating longer groundwater residence times in the order of thousands of years. The Carbon-14/Finke Distance relationship indicates that the Finke River is currently providing an active source of recharge to the J aquifer.

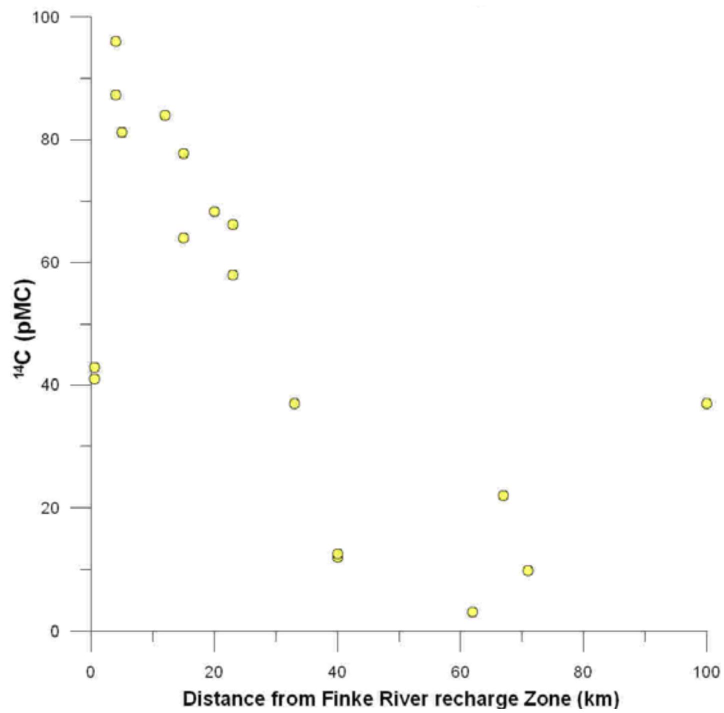


Figure 3-5 Carbon 14 in groundwater versus distance from Finke River

In April of 2010 DLRM drilled a series of targeted bores to quantify recharge to the J aquifer through flooding in the Finke River. The selected study site is located on New Crown Station approximately 15km east of Apatula Community. Five bores were drilled into the watertable and were equipped with water level sensors and loggers. An additional logger was installed in the Finke riverbed adjacent to the bore site.

In October 2010 a significant rainfall event occurred in the Finke Catchment with 110mm falling at New Crown Homestead in the 48 hours to 16th October. The rainfall resulted in a large flow event in the Finke River with bank to bank flow observed in the recharge reach of the river (see **Figure 3-6**). Note the width of the river in this image is approximately 400m.

Figure 3-6 Flow event in the Finke River at the study site 16.10.2010

The flow event was captured in the river bed logger and resulted in a recharge event that was observed in the shallowest bore (RN018593) located directly adjacent to the river. The surface water and groundwater data is presented below in **Figure 3-7**. The two traces show the height of the river in blue and the groundwater level in the J aquifer in red. This flood event resulted in a rise of 3.4m in groundwater levels within the J aquifer.

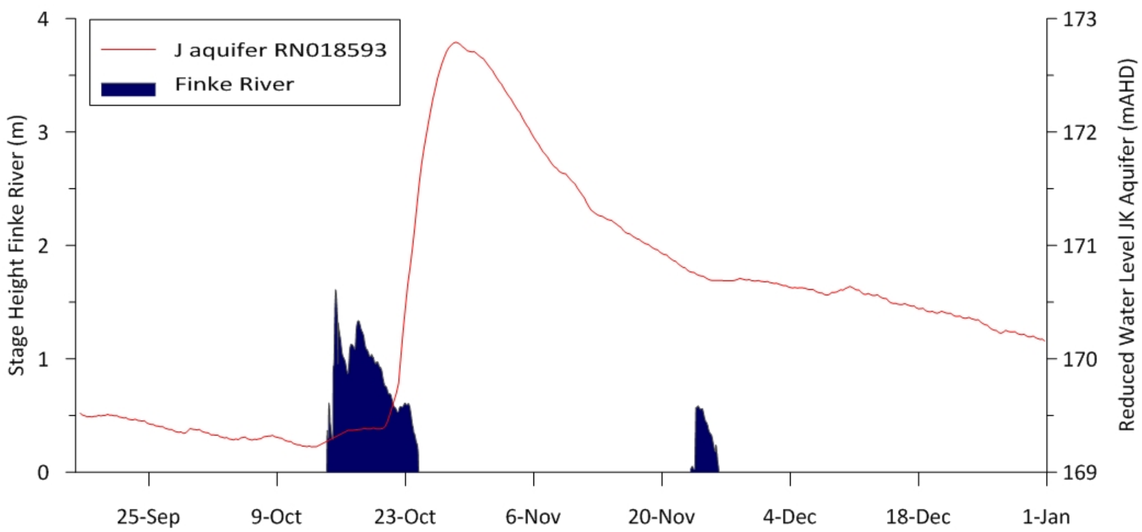


Figure 3-7 Groundwater response to October 2010 flood in the Finke River

This rise in the watertable, the duration of the surface water flow and the lag time between the flow and the watertable rise can be used to calculate a recharge rate for the flood event using an analytical groundwater mounding model based on Hantush (1967). Hantush presented the following analytical solution for predicting the maximum height of a groundwater mound beneath a recharge zone:

$$h^2 - h_0^2 = Z(x, y, t) = \frac{uw}{Kw}\int_0^t \left[erf\left(\frac{\frac{l}{2}+x}{\sqrt{4vt}}\right) + erf\left(\frac{\frac{l}{2}-x}{\sqrt{4vt}}\right)\right]\left[erf\left(\frac{\frac{a}{2}+y}{\sqrt{4vt}}\right) + erf\left(\frac{\frac{a}{2}-y}{\sqrt{4vt}}\right)\right]$$

$$v = \frac{K\overline{b}}{S_y}$$

$$\overline{b} = 0.5\left[h_i(0) + h(t_1)\right]$$

Where: a is the length of the recharge area in y direction (m), h is the head beneath the mound (m), h_0 is the head before recharge commences (m), k is hydraulic conductivity (m/day), l is the length of the recharge area in the x direction (m), S_y is specific yield of the aquifer (dimensionless), t is time (days), t_1 is time used in successive approximations (days), w is the recharge rate (m/day), x and y are the coordinates of the observation point (m).

The equations can be rearranged to solve for the recharge term (w). Due to the absence of aquifer test data the greatest uncertainty in the input terms is associated with the hydraulic conductivity (K) and the Specific Yield (S_y). Sensitivity testing was undertaken to examine the impact of these terms on the recharge estimate; results are presented in **Appendix A** along with the model input terms. The length of the recharge event was taken as 8.5 days, which is the duration the stage height for the logger registered above one metre. For heights below one metre flow is expected to be restricted to a channel and potential recharge is significantly lower. The inputs that best replicate the observed watertable rise in RN018593 result in a calculated recharge rate of 150mm/day. This yields a total recharge of 1275mm for the recharge event.

The Hantush Mounding solution involves several key assumptions. Namely, that the aquifer is unconfined, homogeneous, isotropic and of infinite extent. In addition it assumes that all flow is horizontal. The J aquifer is a well sorted sandstone aquifer and for the purposes of the modelling it is reasonable to assume it is homogeneous and isotropic. It is a massive regional aquifer and given the very local scale of the modelling it will behave as an aquifer of infinite extent. The study site has bores nested with RN018593 and also two down gradient sites. Water level data in the nested site revealed a component of vertical flow during the recharge event - however, it is insignificant compared to the horizontal flow component. The mounding model also assumes the groundwater observation point is located directly under the middle of the groundwater mound. In reality RN018593 is located on the river bank approximately 150m from the centre of the river. The head rise observed under middle of the channel will be greater than that observed in RN018593 and consequently the modelling results will slightly underestimate the recharge rate.

The J aquifer recharge zone for the Finke River is shown in **Figure 3-8**. It spans approximately a 35km reach of the river and an area of 13.3km^2. By assuming that the groundwater mound observed in RN018593 is representative of the watertable rise across the entire recharge zone it is possible to calculate a total recharge volume. For the October 2010 flow event this volume is 17,000ML.

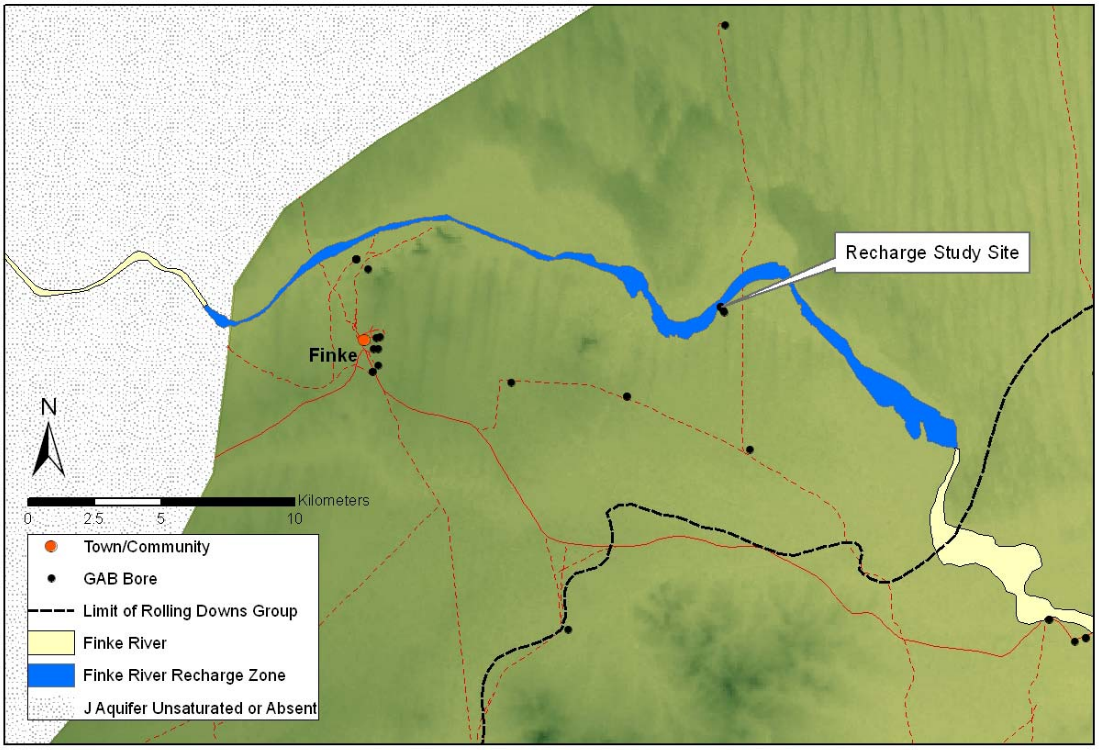


Figure 3-8 Finke River Recharge Zone

Extrapolating recharge from the October 2010 event into an annual recharge rate for the Finke River system is complicated by the irregularity of rainfall and flow events. There are no stream gauges located in the recharge zone and consequently no conclusive record of flow in this part of the catchment. Attempts to directly translate results from rainfall runoff models for the upper catchment were unsuccessful due to the large size of the catchment and transmission losses between the upper and lower catchment.

In the absence of more conclusive data, the hydrograph for the Railway Bridge Crossing gauging station (G0050140) has been used to approximate the frequency of large flow events which result in recharge to the J aquifer (see **Figure 3-9**). Over the period between 2008 and 2010, the significant flood events at Finke Community and New Crown Homestead have been recorded. Full bank flow events over this period include the November 2008, January 2010, March 2010 and October 2010 events. With the exception of October 2010 which was largely driven by rainfall downstream of G0050140, these events all registered a stage height in excess of four metres at the railway bridge crossing. In lieu of more accurate flow data, the four metre stage height at G0050140 has been adopted as a criteria to identify which Finke River flow events contribute significant recharge to the J aquifer. On this basis an analysis of the hydrograph record for G0050140 identifies eight recharge events over the 24 year record period (see **Figure 3-9**). Assuming each event contributes a similar volume of recharge as the October 2010 event (17,000 ML) this results in an annualised recharge of 5650 ML for the Finke River system.

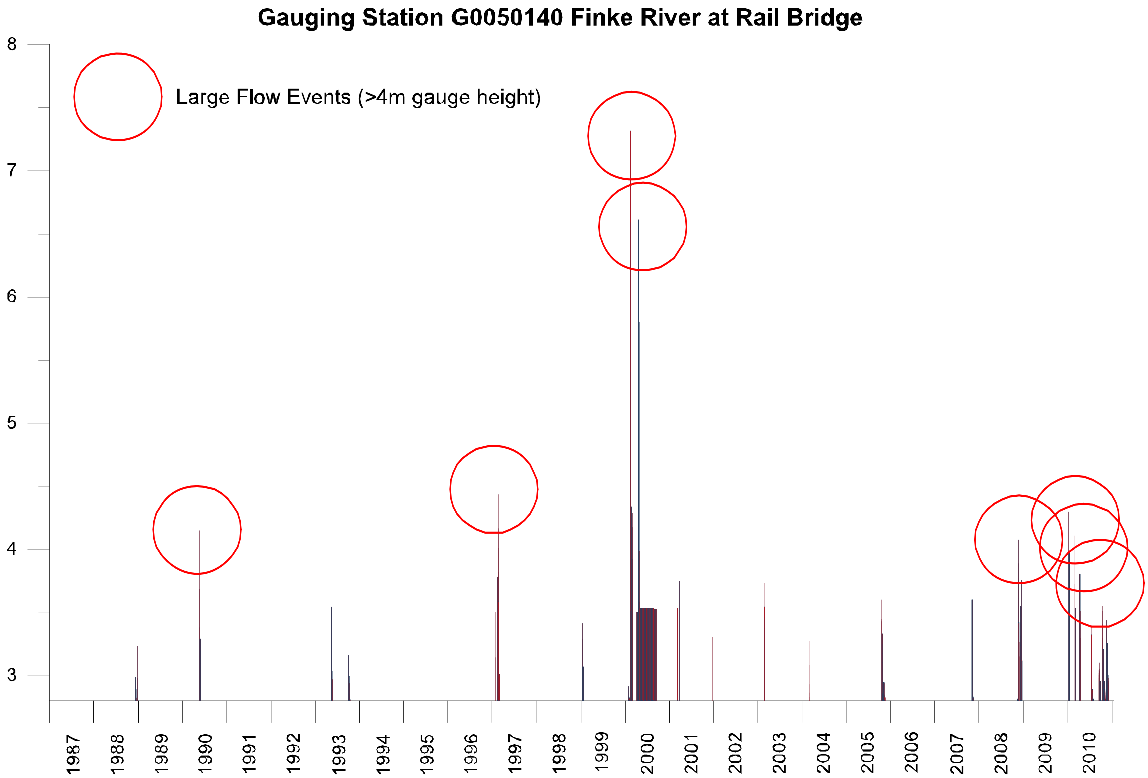


Figure 3-9 Gauge Height record at G0050140 (Finke River Bridge)

NB - Oct 2010 flow event was driven by local runoff, although it falls below the 4m criteria a bank to bank flow water observed.

Recharge Estimates based on Carbon-14 Horizontal Flow Velocities

Recharge rates for the Finke River can also be estimated using Carbon-14 data and calculations based on Vogel (1967). If groundwater samples are obtained from approximately the same depth in the aquifer than the horizontal groundwater flow velocity can be calculated using Carbon 14-ages between wells along a flow path. The horizontal flow velocity is directly proportional to the width of the recharge area, the recharge rate and inversely proportional to the height and porosity of the aquifer. The equation can be rearranged to solve for the recharge rate as follows

$$R = \frac{v_h H \theta}{x}$$

Recharge = Recharge rate in mm per year

x = width of the recharge beds in metres

x2-x1 = distance between groundwater measurements along flow line in metres

H (m) = Aquifer thickness

θ = Porosity (dimensionless)

Three sets of bore pairs were selected to calculate recharge from the Finke River. Each pair is located on a flow line and has contemporaneous Carbon-14 measurements (Figure 3-10).

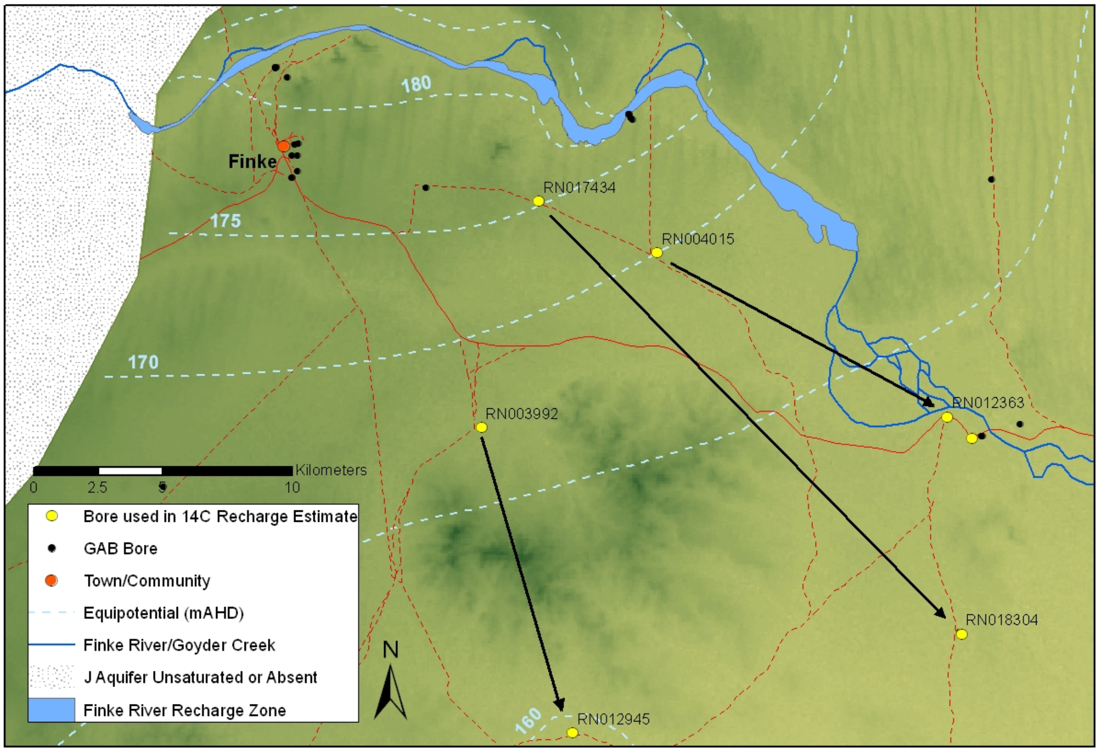


Figure 3-10 Bore pairs used in Carbon 14 recharge estimates for Finke River

The Carbon-14 concentrations were used to calculate a groundwater travel time between each of the bore pairs. The travel time was translated into a horizontal velocity by dividing by the distance between bores within each pair. Results of the groundwater travel time, horizontal velocity and recharge rate are provided in **Table 3-1**, a more detailed description of the calculations and input data is provided in **Appendix B**.

Table 3-1 Carbon-14 Travel Time, Horizontal Velocities and Recharge Rates

Bore Pair	Groundwater Travel Time Between Bores (years)	Horizontal Velocity (m/year)	Recharge Rate (mm/year)
RN003992 to RN012945	1921	6.5	490
RN004015 to RN012363	1716	7.6	850
RN017434 to RN018304	6492	3.6	380

Carbon-14 recharge rates for the Finke River ranged from 380 to 850mm/year (5100 to 11300 ML/year) and compared favourably with recharge rates calculated from the hydraulic methods (presented above).

Recharge Contribution from Other Rivers to J Aquifer

In comparison to the Finke system, there is limited data to assess recharge contribution from the other rivers (i.e. the Hale, Hay, Plenty, Todd Rivers and Illogwa Creek) which flow across the margin of the GAB. Based on an assessment of the surface geology and drilling logs potential for recharge along the Hay, Hale and Todd Rivers appears limited, while conditions along Illogwa Creek and the Plenty River appear more favourable.

In contrast to the Finke area, the Rolling Downs Group in the Hale River region appears to onlap directly onto the Proterozoic Arunta Block. Low permeability mudstone and shale of this formation overlie the J aquifer and restrict the infiltration of Hay River surface water from reaching the J aquifer. No groundwater data exists in the region where the lower Todd River cuts across the GAB aquifer. However, an assessment of topographic maps and satellite images shows that the lower flood out of the Todd system is limited in size and extent in comparison to the neighbouring Hale, Finke and Plenty systems. It is proposed here that under modern day conditions flooding within the Todd River would rarely reach a level where surface water flow is carried over the edge of the GAB. Groundwater conditions along the Hale River are confined and preliminary findings from the "Allocating Water and Maintaining Springs in the GAB Project" have not identified modern groundwater in the vicinity of the Hale River channel suggesting that active recharge from the Hale River is limited at best.

Recent groundwater sampling has identified modern groundwater in the J aquifer around the Plenty River. The hydrogeological setting around Illogwa Creek also appears favourable for the operation of this recharge mechanism. However, available data is insufficient to estimate recharge individually for each of these rivers. In lieu of site specific data this report assumes recharge rates along the Plenty and Illogwa systems are similar to the estimated rate for the Finke River system (5650 ML/year). This results in an annualised recharge for the GAB WCD of 17,000 ML.

The recharge assessment for the GAB WCD is critical as it is being used in the WAP process as a basis for the quantifying the consumptive pool for the J aquifer. While conclusive data is available along the Finke system, recharge estimates in this report are limited by the paucity of data along the other rivers systems. Further investigation and quantification of recharge rates along these systems is recommended.

3.5.3 Recharge Rates to Other Aquifers in the WCD

There is insufficient information available to quantify recharge rates to the alluvial, Rolling Downs Group, Crown Point and Finke Group aquifers.

3.6. Discharge

There is no known natural discharge from the J aquifer in the WCD, although significant discharge occurs through springs in SA and QLD adjacent to the WCD (see **Section 4.3**). Discharge resulting from groundwater extraction is currently estimated at 2210 ML/year. Discharge due to evapotranspiration from the J aquifer is considered to be negligible. This is due to the very deep unsaturated zone in the unconfined portion of the aquifer, which limits the potential for evapotranspiration off the watertable.

3.7. Storage

The absence of local data on specific yield, specific storage and thickness of the J aquifer make it problematic to provide a reasonable storage estimate of the NT GAB resource. The size of the groundwater resource within the J aquifer is significant. However, the confined nature of the aquifer means any substantial groundwater extraction has the potential to significantly impact pressure levels within the aquifer. If a sustained extraction occurs near the border region with either South Australia or Queensland there is potential for impact on GAB springs systems in these states. Locally, within the NT, large sustained extractions may threaten artesian conditions and affect groundwater levels in existing bores. Site specific hydrogeology data is required to quantify aquifer parameters and assess the extent of potential impact resulting from any proposed large groundwater extractions.

4. Resource Management

4.1. Groundwater Bore Use and Estimated Extraction

A total of 182 groundwater bores have been constructed in the WCD[2] over the last 110 years. Of the 182 it is estimated that 52 bores are currently being used for groundwater extraction, 17 bores are actively used in groundwater investigations or monitoring and the remaining 113 bores are either abandoned or are not equipped.

The bores are predominantly used as stock and domestic water supply for pastoral enterprises (71% of bores). Other bore uses in the WCD include: groundwater investigation and monitoring (13%), community and outstation water supply (11%), water supply for mineral exploration (4%) and roads bores (<1%). **Figure 4-1** shows the total number of bores per each use category in the GAB WCD.

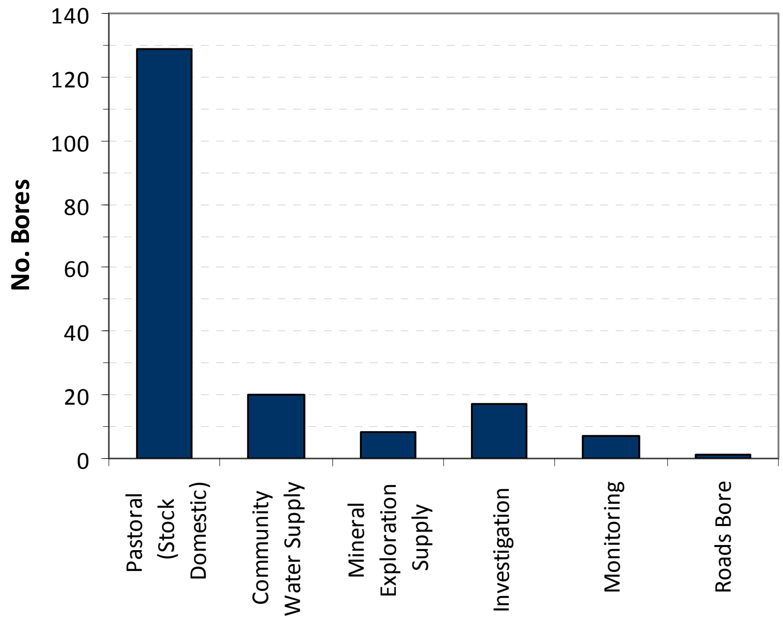


Figure 4-1 Number of bores in each use category for the WCD

Within the WCD groundwater is extracted from multiple aquifers. A breakdown of the number of bores constructed per aquifer is provided in **Figure 4-2**. Around 50% of bores are screened in the J aquifer, this includes bores that extract from the poorer quality groundwater at the top of the Algebuckina Sandstone. The remaining bores source groundwater from aquifers other than the J aquifer, these include: alluvial aquifers (18%), the Crown Point Formation (9%), aquifers within the Rolling Downs Group (9%) and other aquifers (8%). Note that in 9% of bores available information is inadequate to discern which source aquifer.

[2] This excludes mineral bores and dud bores which have not been cased

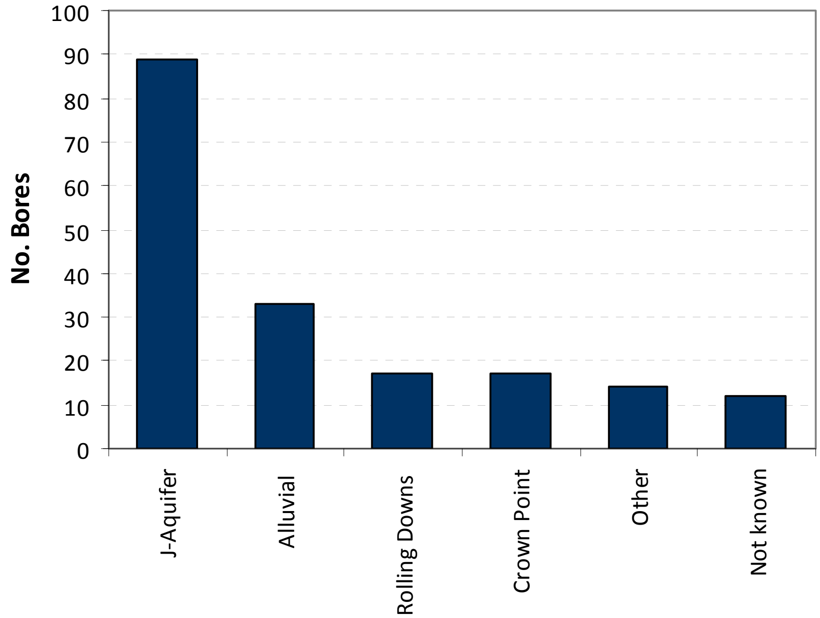
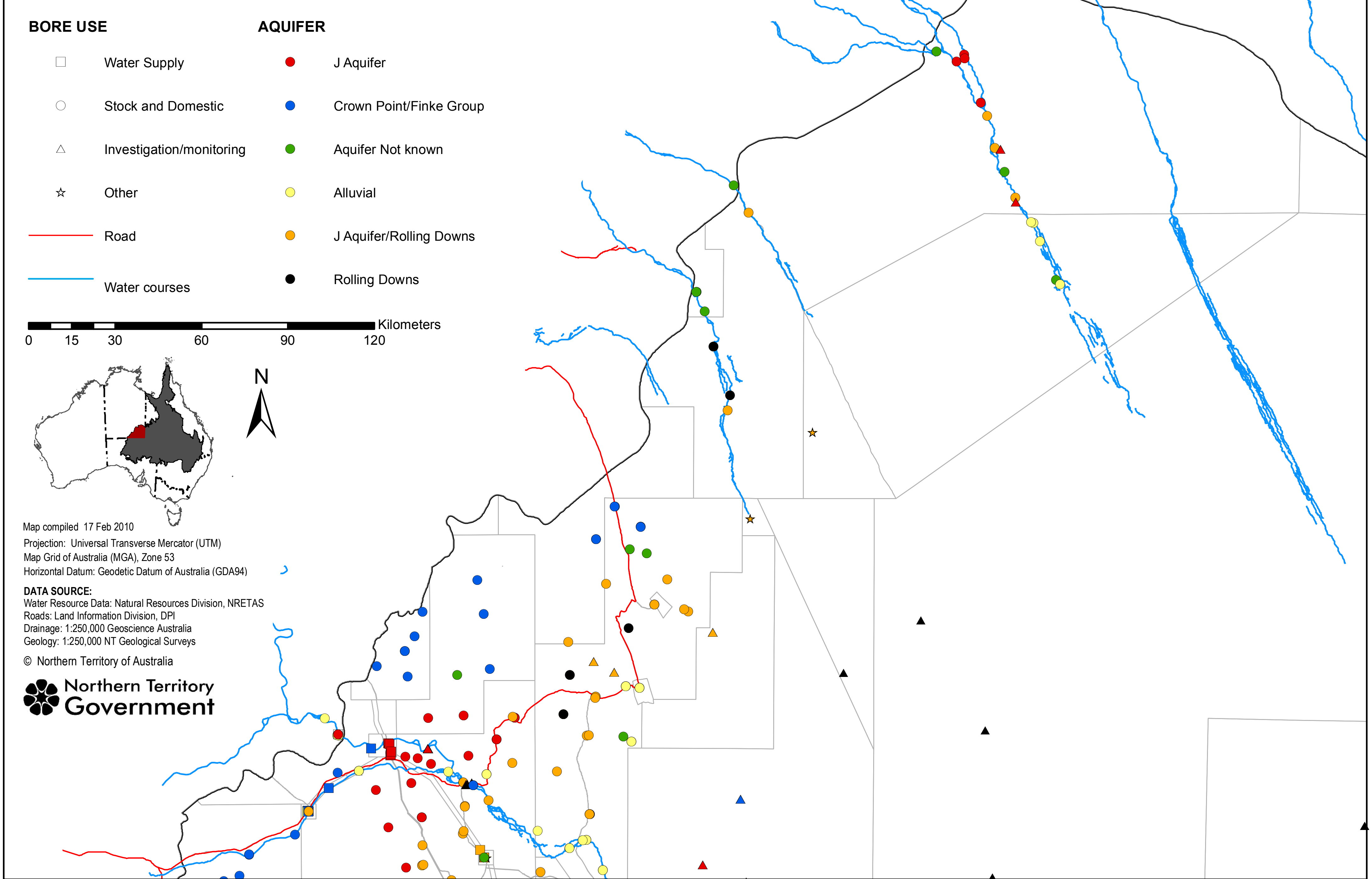


Figure 4-2 Number of bores per aquifer class in the WCD

Current groundwater extraction in the WCD is estimated at 3470 ML/year. Approximately 2210 ML/year is sourced from the J aquifer with a further 1260 ML/year extracted from non-GAB aquifers within the WCD. With respect to extraction from the J aquifer around 1890 ML/year[3] is used for stock and domestic supply, 250 ML/year is consumed in environmental discharge from McDills bore while water supply for Apatula Community accounts for the remaining 70 ML/year.

[3] Stock and Domestic use was estimated assuming a continuous pump rate of 2L/s per stock bore. 30 bores were assessed as extracting groundwater wholly or in part from the J aquifer.

Figure 4-3 GAB WCD Bores by Use and Aquifer



4.2. Groundwater Monitoring Network

There are currently six designated monitoring bores in the GAB WCD. Two bores are located in the unconfined around Finke Community, two bores are in the confined region on Andado Station and two bores are situated on the Pmer Ulperre Ingwemirne Arletherre ALT in the artesian region of the aquifer (see **Figure 4-5**). A summary of these bores, their depths, record length and current status is provided in **Table 4-1**. A more detailed review of the GAB monitoring network was undertaken by DLRM in 2007 in can be found in Wischusen (2007).

Table 4-1 Summary of GAB WCD monitoring bores

Bore ID	Drilled Depth (m)	Standing Water Level (mBNS)	Hydrogeological Zone	Monitoring Record	Current Status
RN016483	125	67.5	Unconfined	2001 - 03, 2006 - 07, 2009 - 2011	Proposed monitoring site
RN004236	143	103	Unconfined	1997 - 99, 2001 - 03, 2006 - 07, 2009 -11	Proposed monitoring site
RN016706	178	22	Confined	1997 - 99, 2001 - 03, 2006	Equipped by station
RN016707	180	15	Confined	1997 - 99, 2001 - 03, 2006	Equipped by station
RN005028	3186	- 28	Confined artesian	2002, 2003, 2006	Not monitored
RN000977	381	- 18	Confined artesian	2002, 2003, 2006	Not monitored

Monitoring of these bores has been discontinuous and this is reflected in their sporadic hydrograph records. Only the two unconfined bores (RN016483 and RN004236) are currently monitored. The limited time series data for RN016483 reveals some variation in water levels over the last decade (**Figure 4-4**). The proximity of this bore to the Finke River suggests that this change in ground water levels may reflect active recharge from the infiltration of flood water in the river. In contrast, water levels in RN016707 have changed little over the ten year monitoring period. The hydrograph for RN016707 may suggest that groundwater levels in the aquifer away from the recharge zones are relatively stable - continuous monitoring is required to confirm this observation. Water level data for the two artesian bores is limited with each bore only having three monitoring events - one in 2002, 2003 and 2006. The pressure level in McDills (RN005028) has risen from 280 kPa in 2002 to 308 kPa in 2006 (28.6m to 31.4m pressure head). This may reflect some recovery in the local potentiometric surface of the J aquifer since the rehabilitation of the bore in 2002. McDills and Anacoora (RN000977) are the only artesian monitoring points in the NT GAB; the regular monitoring of pressure levels in these bores is essential to building a baseline dataset for the aquifer. It is recommended that routine monitoring of all these bores is reinstated.

In addition to the six designated monitoring bores an additional nine investigation bores have been drilled at two sites on New Crown Station. These bores were installed to investigate preferential recharge to the J aquifer from the Finke River (see **Section 3.5**). These bores were monitored between 2009 and 2011 and it is recommended that at least one bore from each of the two sites is maintained as such.

Geographically, the existing monitoring bores are clustered in the south-west of the WCD and do not provide an adequate spatial coverage of the aquifer. The absence of monitoring points in the east of the WCD reflects the remoteness and inaccessibility of the Simpson Desert, in addition to the significant depth of the aquifer in this region. It is unlikely the network can be readily extended to cover this area. However, there is potential for additional monitoring points in the north and north-west of the WCD. Increasing the spatial coverage of the monitoring network and ensuring bores are routinely monitored is critical in determining the state and flux of the groundwater resource.

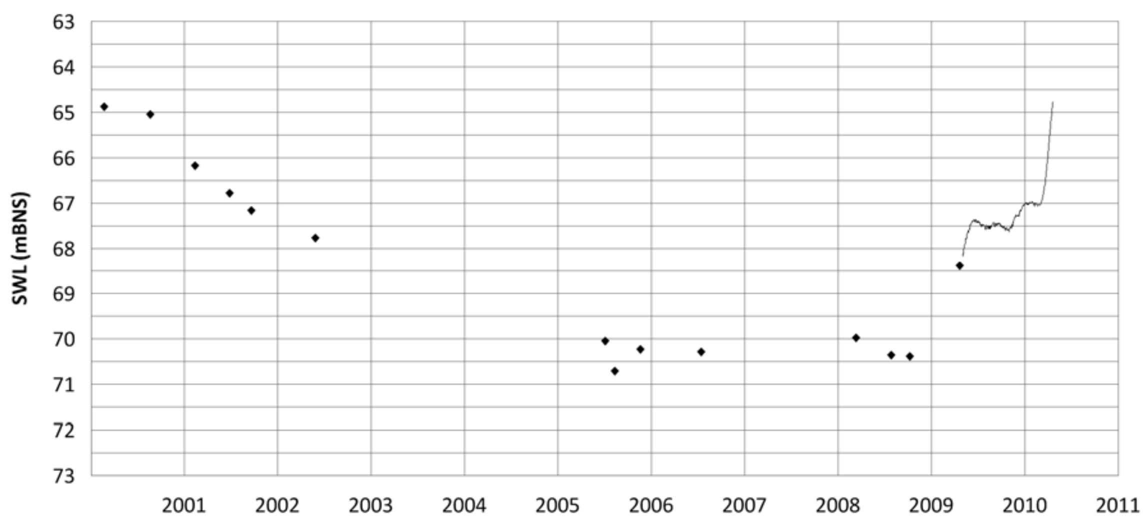
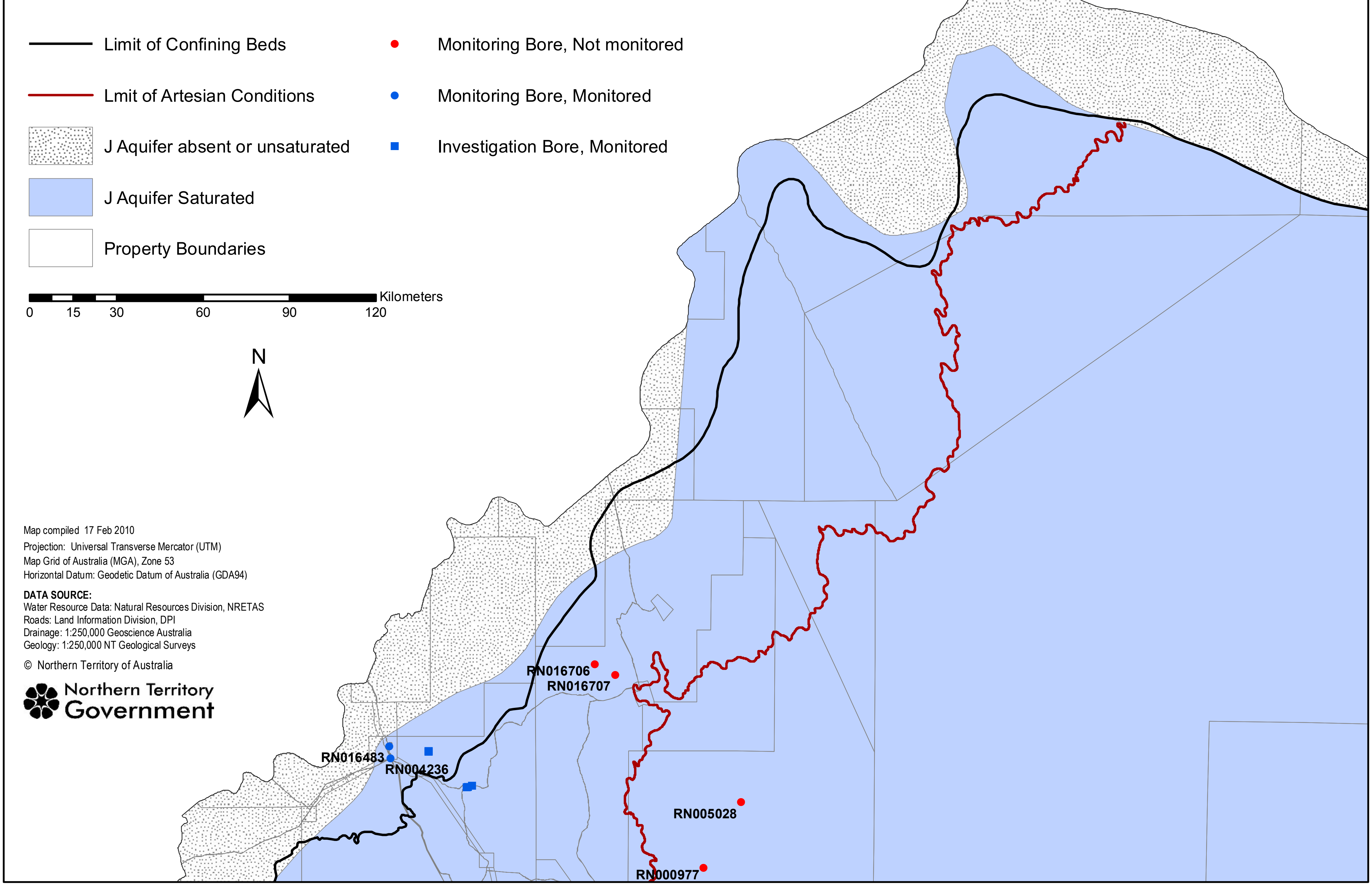


Figure 4-4 Hydrograph for RN16483

It is also recommended that a monitoring bore be established on the NT/SA border north of Dalhousie Springs. These springs are a RAMSAR listed wetland and are protected under the Federal Environmental Protection and Biodiversity Conservation (EPBC) Act. The current coverage of the monitoring network is inadequate to identify if any future groundwater allocation granted under the WAP will impact on Dalhousie Springs.

Figure 4-5 J Aquifer Monitoring Bores



4.3. Groundwater Dependant Ecosystems (GDEs)

4.3.1 J Aquifer

There are no known natural ecosystems dependent on groundwater from the J aquifer in the WCD. However, significant groundwater dependent ecosystems (GDEs) occur close to the NT/SA border at Dalhousie Springs and the NT/QLD border at the Mulligan River Supergroup.[4]

The Dalhousie Springs Supergroup is located 70km south of the WCD. It contains over 100 individual springs with a cumulative discharge in excess of 150 L/s (Cox and Barron, 1998). The Dalhousie supergroup constitutes 90% of natural spring discharge in the SA portion of the GAB (Ponder and Zeidler, 1989). It is a significant GDE which is home to a number of endemic species including two fish and three crustaceans, in addition to snail and invertebrate species (Cox and Barron, 1998).

The Mulligan River Spring Supergroup is located in Queensland approximately 100km east of the WCD. The supergroup contains 23 active springs in 12 recorded spring complexes with four springs supporting wetlands between 0.1 and 0.5 Ha in area (Fensham and Fairfax, 2003). Fensham and Price (2004) report endemic species in at least one spring fed wetland (Post Spring Complex).

The WCD contains one manmade GDE – McDills bore fed wetland. McDills bore is an oil exploration well that was drilled in 1965 in the southwest of the WCD. During drilling the well casing was perforated adjacent to the J aquifer to provide a water supply for the operation (Amerada, 1965). At the completion of drilling three cement plugs were installed and 40 bags of cement was pumped down the casing annulus to seal the flow. The casing was capped at the surface with a metal plate and a pressure valve to control the flow. Despite these measures shortly after the well was abandoned the surface casing failed creating an uncontrolled flow at the surface. In 2002 outflow from the well was gauged at 120 L/s, the footprint of the wetland associated with the bore was estimated at 30 Ha (Humphreys and Kunde, 2004). The bore was rehabilitated in 2002 by the NT Government. During the rehabilitation a 40mm stainless steel pipe was installed in the bore headworks to provide a controlled environmental flow of 8 L/s. This flow maintains a small wetland, which in 2006 was estimated at 0.75 Ha in size.

4.3.2 Other

The shallow alluvial aquifers connected to major water courses in the WCD are likely to play a key role in supporting riparian forests. The forests generally consist of River Red Gum *(Eucalyptus camaldensus)*, Coolibah *(Eucalyptus coolabah)* and Teatree *(Melaleuca spp.)*. Significant communities occur along the Finke, Plenty, Hale and Hay Rivers and can be extensive in area. The riparian forest associated with the Finke River flood-out is estimated to extend for 20km in length and reach 6km at its widest point. While the forests harvest surface water from infrequent flood events in the rivers they are likely to be highly dependant on alluvial groundwater during the periods between flow events. Little is currently known

[4] A Supergroup is a major regional cluster of spring-complexes with some consistent hydrogeological characteristics, these were initially defined and named as 11 ‘spring groups’ by Habermehl’s (1982) and were termed “supergroups” by Ponder (1986).

about the extent, quality and permanence of groundwater in the alluvial aquifer systems in the WCD.

5. Conclusions and Recommendations

5.1. Conclusions

The Great Artesian Basin Water Control District is located in the far south-east corner of the Northern Territory and covers around 5% of the Great Artesian Basin. The area is remote and is sparsely populated with only an estimated 350 people living within the WCD. Land use is split between pastoral cattle grazing along the outer margin of the WCD, Aboriginal Land Trusts and vacant crown land. A large proportion of the area is covered by the dune fields of the Simpson Desert which limit access and development opportunity. The climate is arid and harsh, with average rainfall between 150 - 300mm/year - in contrast, annual evaporation rates exceed 3000mm. There are several significant ephemeral river systems which drain internally into the Simpson Desert. Irregular flooding in these rivers represents an important recharge process to the GAB aquifer.

The GAB sequence is part of the Eromanga geological basin, which overlies the Permian aged Pedirka basin and underlies sediments of the Lake Eyre Basin. The GAB outcrops along the western and northern margins of the WCD and dips to the south and east reaching depths of up to 2260m below the surface close to the NT, SA, QLD border. The main geological components of the Eromanga Basin are the Rolling Downs Group, Cadna-Owie Formation, the Algebuckina Sandstone and the Poolowanna Formation. The latter three units for the major Cretaceous/Jurassic aged aquifer in the WCD, which is referred to in this report as the J aquifer. Lesser groundwater resources are present in the Rolling Downs Group, the Permian Crown Point Formation, the Devonian Finke group and Quaternary and Tertiary alluvial aquifers.

The J aquifer is a highly transmissive porous media sandstone aquifer that is present across the majority of the WCD. It forms the most significant and largely only potable groundwater resource in the WCD. The J aquifer is unconfined on the edges of the WCD and becomes confined and then artesian towards the south east. Information on aquifer parameters (transmissivity, hydraulic conductivity, storage coefficients) for the NT portion of the J aquifer is limited. The geometry and thickness of the aquifer are also poorly defined, especially in the east of the WCD. Regional flow direction within the J aquifer is to the southeast, away from the margins of the basin and toward the SA and QLD borders. Regional groundwater gradients are low being in the order of 0.0003.

Current day recharge to the J aquifer occurs via the infiltration of flood water from desert rivers where they intersect the outcropping J aquifer on the margin of the WCD. Diffuse recharge is considered to be negligible due to the very low rainfall and extremely high potential evaporation rate. Recharge along the Finke River is estimated at 5650 ML/year, the recharge mechanism is also thought to operate along the less well studied Plenty River and Illogwa Creek. Total recharge to the J aquifer is estimated at 17,000 ML/year.

Current discharge from the J aquifer is estimated at 2210ML/year. This consists of licensed groundwater extraction, stock and domestic extraction and a small environmental allocation. There is no known natural groundwater discharge within the NT, although there is significant discharge from spring complexes close to the border at Dalhousie Springs (SA) and Mulligan River Springs (QLD). Information on storage coefficients is extremely limited and as such the storage capacity of the J aquifer cannot be accurately quantified.

Since 1890 approximately 182 groundwater bores have been drilled in the WCD, over 70% of all bores have been installed to provide stock and domestic supply. At present only 52 bores actively extract from groundwater within the WCD. Groundwater is pumped from a number of distinct aquifer systems although over 50% of all active bores extract from the J aquifer. Total bore extraction for the WCD is estimated at 3470ML/year, of which 2210ML (or 64%) is pumped from the J aquifer.

The GAB WCD monitoring network currently consists of six monitoring bores, with two bores in the unconfined, confined and artesian area. To date monitoring has been sporadic and irregular, only two of these bores are currently monitored. The absence of time series water level data for the J aquifer makes it difficult to establish a baseline condition for the aquifer, which will be critical in assessing the impact of future water allocations within the WCD under the WAP. The monitoring network is also currently concentrated in the southeast corner of the WCD and does not provide adequate spatial coverage of the J aquifer.

5.2. Uncertainty/Limitations

There are a number of limitations and uncertainties associated with this assessment and the level of data available.

- There is no information available on the hydraulic conductivity, specific yield or storage coefficients for the Algebuckina Sandstone within the Northern Territory. Estimates have been made based on modelled data and these conform well with text book values for the relevant aquifer lithology. This information is critical to the calculated recharge rates and increases the uncertainty associated with these estimates.
- Existing bore data is concentrated on the south-west and western margin of the WCD. The reliability of the potentiometric surface for the J aquifer in the eastern and northern areas is very low and it should be viewed as a regional guide at best.
- There is no information available on the interconnections or gradient between the J aquifer and the underlying Permian formations (Purni and Crown Point Formations). These units are the target for gas and coal exploration, should any mineral or gas extraction occur in these units this information will be essential to assessing the impact on groundwater levels within the J aquifer.
- Recharge rates calculated in this report are approximates at best. Rates are based on the observation of a single recharge event in the Finke River in an exceptionally wet year and don't consider the dynamic of the recharge process under different size and duration flow events. Rates from the Finke River have been extrapolated to other catchments where the limited data available indicates that it may be reasonable to assume that a similar recharge process is in effect.
- There is very limited monitoring data - both with respect to time series records and as a spatial coverage of the aquifer. This baseline information will be critical to examining and assessing the impact of any new development or potential extraction within the WCD.

5.3. Recommendations

Monitoring

The monitoring network needs to be enhanced to provide good spatial coverage of the J aquifer and coverage of the critical hydrogeological zones in the aquifer. It is recommended that this involves:

- Routine monitoring should recommence at all existing monitoring sites, especially at the artesian sites (McDills and Anacoora).
- Key monitoring sites are established in the confined portion of the aquifer - of particular important is the establishment of a confined monitoring bore in the J aquifer near the SA border up gradient from Dalhousie Springs. The network should also be augmented to provide monitoring points in the north and north western areas of the aquifer.
- Baseline data needs to be collated before any large groundwater extraction occurs in the NT.
- Installation or re-instatement of gauges on the Finke, Hale, Plenty Rivers as well as Illogwa Creek in the recharge section of the basin (rather than just upstream of the WCD). Stage height data and corresponding flow in these reaches is critical for establishing a relationship between groundwater recharge and ephemeral flooding.

Bore Construction

Saline groundwater found in sandy interbeds in the Rolling Downs Group poses a water quality threat to the potable supplies in the J aquifer. Bores in the confined portion of the aquifer need to have a construction that adequately prevents inter-aquifer leakage. The most robust solution is to require bores in the confined area to have the Rolling Downs Group cased and cemented off to prevent downward leakage of groundwater.

Aquifer Parameters

Efforts should be made to improve estimates of aquifer parameters (transmissivity, hydraulic conductivity, storage coefficients). This information is critical in assessing recharge rates and estimating the effect of future groundwater extractions.

Recharge Investigations

The recharge assessment for the GAB WCD is critical as it is being used in the WAP process as a basis for the quantifying the consumptive pool for the J aquifer. While conclusive data is available along the Finke system, recharge estimates in this report are limited by the paucity of data along the other rivers systems. Further investigation and quantification of recharge rates along these systems is recommended.

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Appendix A Hantush Mounding Recharge Rates

Recharge modelling was undertaken using the "Mounding" module in pump test analysis software Aqtesolve Pro Version 4.5. The equations underpinning the solution are provide below in addition to the input parameters for the final modelling results and graphs of the sensitivity testing undertaken on K and S_y parameters.

$$h^2 - h_0^2 = Z(x,y,t) = \frac{\upsilon w}{K} \int_0^t \left[erf\left(\frac{l/2+x}{\sqrt{4\upsilon t}}\right) + erf\left(\frac{l/2-x}{\sqrt{4\upsilon t}}\right) \right] \left[erf\left(\frac{a/2+y}{\sqrt{4\upsilon t}}\right) + erf\left(\frac{a/2-y}{\sqrt{4\upsilon t}}\right) \right]$$

$$\upsilon = K\bar{b} / S_y$$

$$\bar{b} = 0.5[h_i(0) + h(t_1)]$$

where

- a is dimension of the recharge area in y direction [L]
- h is the head beneath the mound [L]
- h_0 is the static head prior to recharge (i.e., initial saturated thickness of aquifer) [L]
- K is the hydraulic conductivity of the aquifer [L/T]
- l is dimension of the recharge area in x direction [L]
- S_y is the specific yield of the aquifer [dimensionless]
- t is time [T]
- t_1 is time used in successive approximation [T]
- w is the recharge rate [L/T]
- x is coordinate of the observation point [L]
- y is coordinate of the observation point [L]

The decay of the water table is found using the principle of superposition (Hantush 1967):

$$h^2 - h_0^2 = Z(x,y,t) - Z(x,y,t-t_0)$$

where

- t_0 is the time when recharge stops [T]

Table 6-1 Input parameters for Hantush recharge modelling

Model Parameter	Description	Input Value
a	Dimension in x direction (m)	250
l	Dimension in y direction (m)	3000
h	Head beneath the mound (m)	85
h0	Initial Saturated Thickness (m)	85
K	Hydraulic Conductivity (m/day)	10
Sy	Specific Yield	0.20
T	Length of simulation (days)	30
t (o)	Time when recharge stops (days)	8.5
X	X coordinate at centre of recharge area	0
Y	Y coordinate at centre of recharge area	0
W	Recharge rate (m/day)	0.15

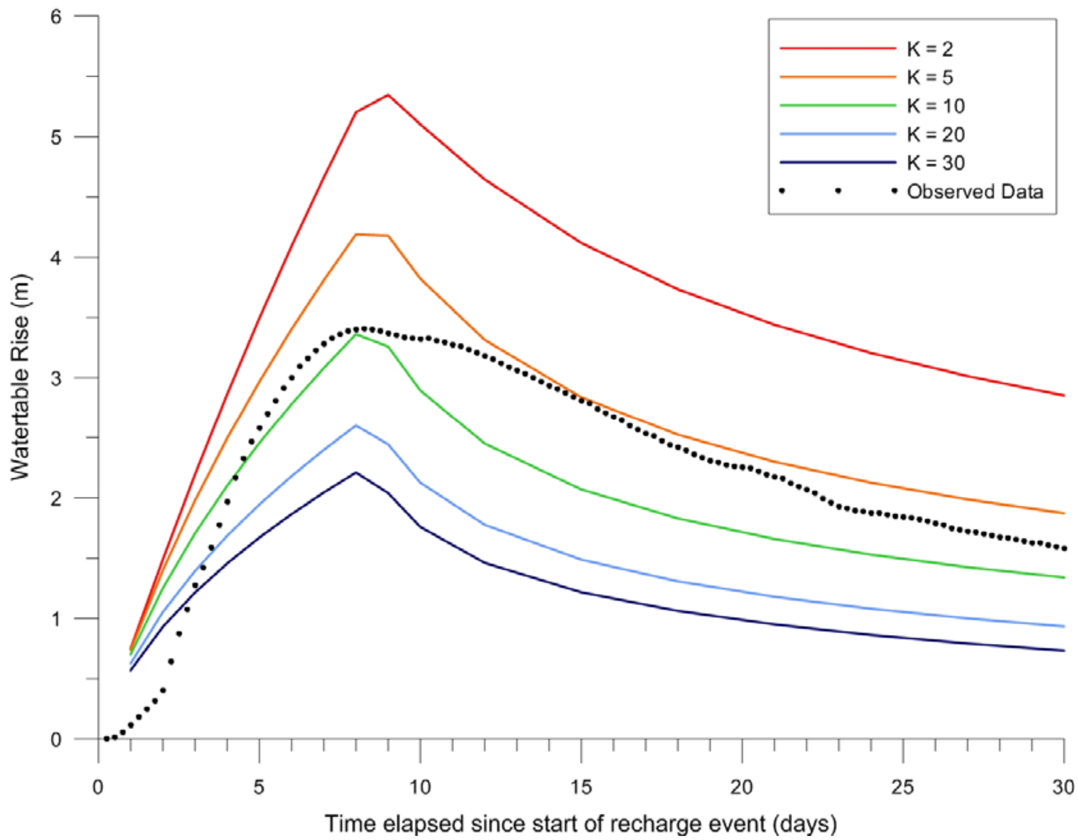

Figure 6-1 Modelling results showing varying K values and observed data

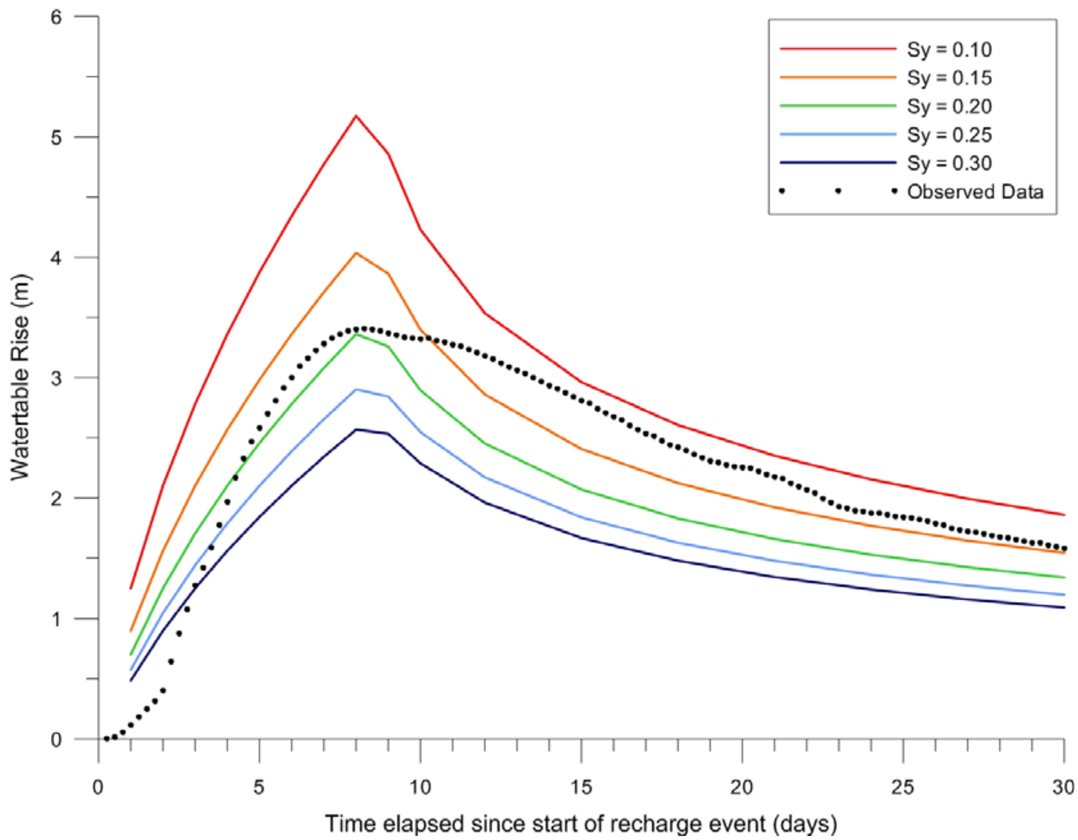

Figure 6-2 Modelling results showing varying Sy values and observed data

Appendix B Vogel Recharge Rates

Carbon-14 and Uncorrected Ages

The following table presents the Carbon-14 (^{14}C) data and uncorrected groundwater age for each bore used to calculate the Vogel recharge rates.

Table 6-2 14C concentrations and uncorrected 14C groundwater ages

BORE ID	14C (PMC)	Calibrated 14C Age (years)
RN003992	82	1417
RN004015	81	1494
RN012363	68	3210
RN012945	67	3338
RN017434	85	1229
RN018304	42	7721

Vogel Equations for Estimating Recharge Rates

The Vogel Equations used below are generally applied to confined aquifers. In the case of the GAB aquifer at Finke the aquifer is unconfined, however, due to the arid climate it is assumed that recharge down flow path of the river channel is negligible. As a consequence it is believed that the Vogel confined aquifer equations are more appropriate than the unconfined aquifer equations for calculating recharge rates in this scenario.

$$v_h = \frac{x_2 - x_1}{t_2 - t_1}$$

and

$$R = \frac{v_h H \theta}{x}$$

Where:

x = width of the recharge beds in metres

x2-x1 = distance between groundwater measurements along flow line in metres

H (m) = Aquifer thickness

θ = Porosity (dimensionless)

t2 - t2 = difference in apparent groundwater age between measurement points in years

vh = Horizontal groundwater velocity in metres per year

Recharge = Recharge rate in mm per year

Table 6-3 Input data for the calculation of recharge rates from the three bore pairs

From	To	x (m)	x2-x1 (m)	H (m)	□	t2-t1 (years)	vh (m/year)	Recharge (mm/year)
RN003992	RN012945	400	12500	200	0.22	1921	6.5	485
RN004015	RN012363	400	13000	200	0.22	1716	7.6	848
RN017434	RN018304	400	23500	200	0.22	6492	3.6	383